DE2 Development and Education Board

User Manual

Version 1.4
Copyright © 2006 Altera Corporation

CONTENTS

Chapter 1 DE2 Package 1

1.1 Package Contents 1
1.2 The DE2 Board Assembly 2
1.3 Getting Help 3

Chapter 2 Altera DE2 Board 4

2.1 Layout and Components 4
2.2 Block Diagram of the DE2 Board 5
2.3 Power-up the DE2 Board 9

Chapter 3 DE2 Control Panel 10

3.1 Control Panel Setup 11
3.2 Controlling the LEDs, 7-Segment Displays and LCD Display 13
3.3 SDRAM/SRAM Controller and Programmer 14
3.4 Flash Memory Programmer 16
3.5 Overall Structure of the DE2 Control Panel 17
3.6 TOOLS – Multi-Port SRAM/SDRAM/Flash Controller 19
3.7 VGA Display Control 20

Chapter 4 Using the DE2 Board 24

4.1 Configuring the Cyclone II FPGA 24
4.2 Using the LEDs and Switches 26
4.3 Using the 7-segment Displays 30
4.4 Clock Inputs 32
4.5 Using the LCD Module 33
4.6 Using the Expansion Header 35
4.7 Using VGA 37
4.8 Using the 24-bit Audio CODEC 41
4.9 RS-232 Serial Port 42
4.10 PS/2 Serial Port 42
4.11 Fast Ethernet Network Controller 43
4.12 TV Decoder 44
4.13 Implementing a TV Encoder 46
4.14 Using USB Host and Device 46
4.15 Using IrDA 48
4.16 Using SDRAM/SRAM/Flash 49

Chapter 5 Examples of Advanced Demonstrations 54

5.1 DE2 Factory Configuration 54

5.2 TV Box Demonstration 55
5.3 USB Paintbrush 57
5.4 USB Device 59
5.5 A Karaoke Machine 61
5.6 Ethernet Packet Sending/Receiving 62
5.7 SD Card Music Player 64
5.8 Music Synthesizer Demonstration 66

Chapter 1
DE2 Package

The DE2 package contains all components needed to use the DE2 board in conjunction with a computer that runs the Microsoft Windows software.

1.1 Package Contents

Figure 1.1 shows a photograph of the DE2 package.

Figure 1.1. The DE2 package contents.

The DE2 package includes:

- DE2 board
- USB Cable for FPGA programming and control
- CD-ROM containing the DE2 documentation and supporting materials, including the User Manual, the Control Panel utility, reference designs and demonstrations, device datasheets, tutorials, and a set of laboratory exercises
- CD-ROMs containing Altera's Quartus® II Web Edition and the Nios® II Embedded Design Suit Evaluation Edition software.
- Bag of six rubber (silicon) covers for the DE2 board stands. The bag also contains some extender pins, which can be used to facilitate easier probing with testing equipment of the board's I/O expansion headers
- Clear plastic cover for the board
- 9V DC wall-mount power supply

1.2 The DE2 Board Assembly

To assemble the included stands for the DE2 board:

- Assemble a rubber (silicon) cover, as shown in Figure 1.2, for each of the six copper stands on the DE2 board
- The clear plastic cover provides extra protection, and is mounted over the top of the board by using additional stands and screws

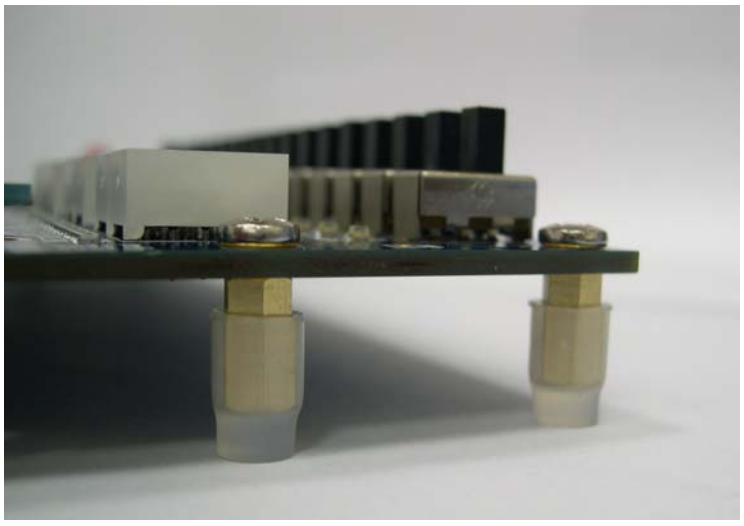

Figure 1.2. The feet for the DE2 board.

1.3 Getting Help

Here are the addresses where you can get help if you encounter problems:

- Altera Corporation
  101 Innovation Drive
  San Jose, California, 95134 USA
  Email: university@altera.com

- Terasic Technologies
  No. 356, Sec. 1, Fusing E. Rd.
  Jhubei City, HsinChu County, Taiwan, 302
  Email: support@terasic.com
  Web: DE2.terasic.com

- Arches Computing
  Unit 708-222 Spadina Ave
  Toronto, Ontario, Canada M5T3A2
  Email: DE2support@archescomputing.com
  Web: DE2.archescomputing.com

A BBS (Bulletin Board System) Forum for the DE2 board has been created at the address shown below. This Forum is meant to serve as a repository for information about the DE2 board, and to provide a resource through which users can ask questions, and share design examples.

- BBS forum: http://www.terasic.com/english/discuss.htm

Chapter 2
Altera DE2 Board

This chapter presents the features and design characteristics of the DE2 board.

2.1 Layout and Components

A photograph of the DE2 board is shown in Figure 2.1. It depicts the layout of the board and indicates the location of the connectors and key components.

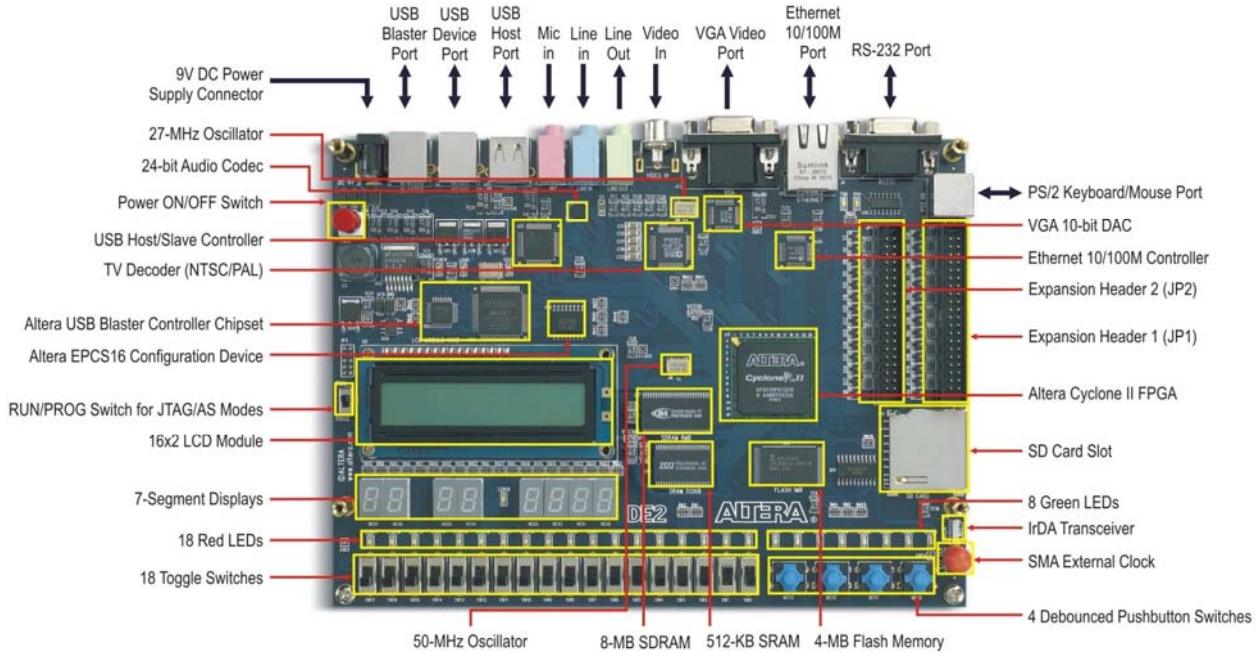

Figure 2.1. The DE2 board.

The DE2 board has many features that allow the user to implement a wide range of designed circuits, from simple circuits to various multimedia projects.

The following hardware is provided on the DE2 board:

- Altera Cyclone® II 2C35 FPGA device
- Altera Serial Configuration device - EPCS16
- USB Blaster (on board) for programming and user API control; both JTAG and Active Serial (AS) programming modes are supported
- 512-Kbyte SRAM
- 8-Mbyte SDRAM

- 4-Mbyte Flash memory (1 Mbyte on some boards)
- SD Card socket
- 4 pushbutton switches
- 18 toggle switches
- 18 red user LEDs
- 9 green user LEDs
- 50-MHz oscillator and 27-MHz oscillator for clock sources
- 24-bit CD-quality audio CODEC with line-in, line-out, and microphone-in jacks
- VGA DAC (10-bit high-speed triple DACs) with VGA-out connector
- TV Decoder (NTSC/PAL) and TV-in connector
- 10/100 Ethernet Controller with a connector
- USB Host/Slave Controller with USB type A and type B connectors
- RS-232 transceiver and 9-pin connector
- PS/2 mouse/keyboard connector
- IrDA transceiver
- Two 40-pin Expansion Headers with diode protection

In addition to these hardware features, the DE2 board has software support for standard I/O interfaces and a control panel facility for accessing various components. Also, software is provided for a number of demonstrations that illustrate the advanced capabilities of the DE2 board.

In order to use the DE2 board, the user has to be familiar with the Quartus II software. The necessary knowledge can be acquired by reading the tutorials *Getting Started with Altera's DE2 Board* and *Quartus II Introduction* (which exists in three versions based on the design entry method used, namely Verilog, VHDL or schematic entry). These tutorials are provided in the directory *DE2_tutorials* on the **DE2 System CD-ROM** that accompanies the DE2 board and can also be found on Altera's DE2 web pages.

2.2 Block Diagram of the DE2 Board

Figure 2.2 gives the block diagram of the DE2 board. To provide maximum flexibility for the user, all connections are made through the Cyclone II FPGA device. Thus, the user can configure the FPGA to implement any system design.

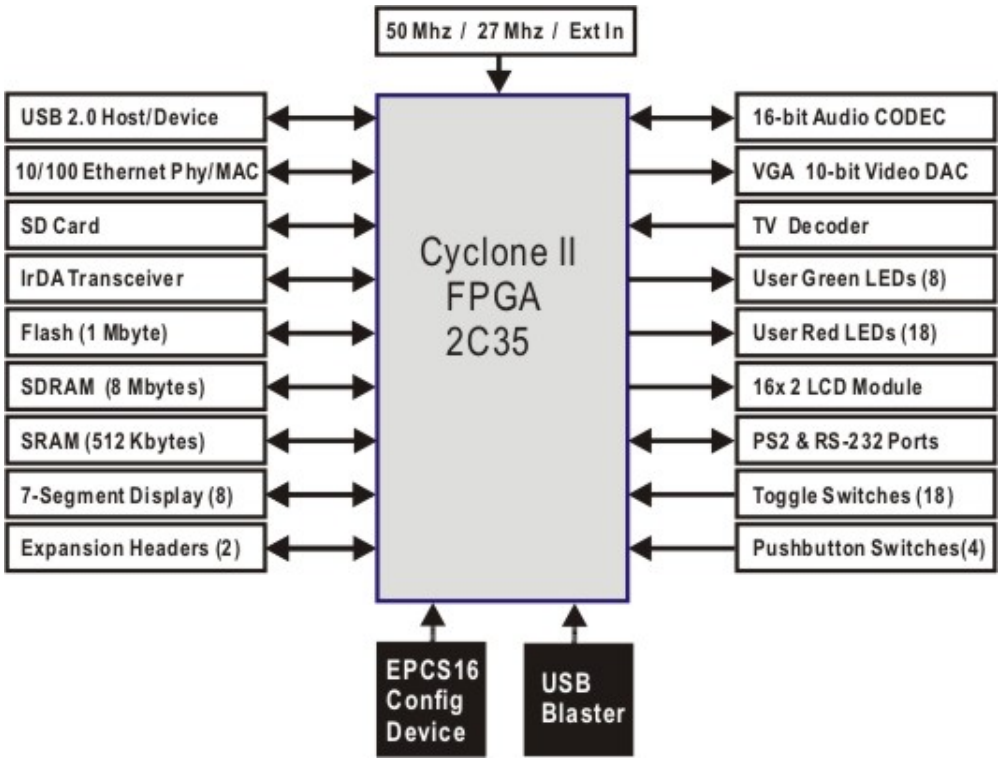

Figure 2.2. Block diagram of the DE2 board.

Following is more detailed information about the blocks in Figure 2.2:

Cyclone II 2C35 FPGA

- 33,216 LEs
- 105 M4K RAM blocks
- 483,840 total RAM bits
- 35 embedded multipliers
- 4 PLLs
- 475 user I/O pins
- FineLine BGA 672-pin package

Serial Configuration device and USB Blaster circuit

- Altera's EPCS16 Serial Configuration device
- On-board USB Blaster for programming and user API control
- JTAG and AS programming modes are supported

SRAM

- 512-Kbyte Static RAM memory chip
- Organized as 256K x 16 bits
- Accessible as memory for the Nios II processor and by the DE2 Control Panel

SDRAM

- 8-Mbyte Single Data Rate Synchronous Dynamic RAM memory chip
- Organized as 1M x 16 bits x 4 banks
- Accessible as memory for the Nios II processor and by the DE2 Control Panel

Flash memory

- 4-Mbyte NOR Flash memory (1 Mbyte on some boards)
- 8-bit data bus
- Accessible as memory for the Nios II processor and by the DE2 Control Panel

SD card socket

- Provides SPI mode for SD Card access
- Accessible as memory for the Nios II processor with the DE2 SD Card Driver

Pushbutton switches

- 4 pushbutton switches
- Debounced by a Schmitt trigger circuit
- Normally high; generates one active-low pulse when the switch is pressed

Toggle switches

- 18 toggle switches for user inputs
- A switch causes logic 0 when in the DOWN (closest to the edge of the DE2 board) position and logic 1 when in the UP position

Clock inputs

- 50-MHz oscillator
- 27-MHz oscillator
- SMA external clock input

Audio CODEC

- Wolfson WM8731 24-bit sigma-delta audio CODEC
- Line-level input, line-level output, and microphone input jacks
- Sampling frequency: 8 to 96 KHz
- Applications for MP3 players and recorders, PDAs, smart phones, voice recorders, etc.

VGA output

- Uses the ADV7123 240-MHz triple 10-bit high-speed video DAC
- With 15-pin high-density D-sub connector
- Supports up to 1600 x 1200 at 100-Hz refresh rate
- Can be used with the Cyclone II FPGA to implement a high-performance TV Encoder

NTSC/PAL TV decoder circuit

- Uses ADV7181B Multi-format SDTV Video Decoder
- Supports NTSC-(M,J,4.43), PAL-(B/D/G/H/I/M/N), SECAM
- Integrates three 54-MHz 9-bit ADCs
- Clocked from a single 27-MHz oscillator input
- Supports Composite Video (CVBS) RCA jack input.
- Supports digital output formats (8-bit/16-bit): ITU-R BT.656 YCrCb 4:2:2 output + HS, VS, and FIELD
- Applications: DVD recorders, LCD TV, Set-top boxes, Digital TV, Portable video devices

10/100 Ethernet controller

- Integrated MAC and PHY with a general processor interface
- Supports 100Base-T and 10Base-T applications
- Supports full-duplex operation at 10 Mb/s and 100 Mb/s, with auto-MDIX
- Fully compliant with the IEEE 802.3u Specification
- Supports IP/TCP/UDP checksum generation and checking
- Supports back-pressure mode for half-duplex mode flow control

USB Host/Slave controller

- Complies fully with Universal Serial Bus Specification Rev. 2.0
- Supports data transfer at full-speed and low-speed
- Supports both USB host and device
- Two USB ports (one type A for a host and one type B for a device)

- Provides a high-speed parallel interface to most available processors; supports Nios II with a Terasic driver

- Supports Programmed I/O (PIO) and Direct Memory Access (DMA)

Serial ports

- One RS-232 port
- One PS/2 port
- DB-9 serial connector for the RS-232 port
- PS/2 connector for connecting a PS2 mouse or keyboard to the DE2 board

IrDA transceiver

- Contains a 115.2-kb/s infrared transceiver
- 32 mA LED drive current
- Integrated EMI shield
- IEC825-1 Class 1 eye safe
- Edge detection input

Two 40-pin expansion headers

- 72 Cyclone II I/O pins, as well as 8 power and ground lines, are brought out to two 40-pin expansion connectors
- 40-pin header is designed to accept a standard 40-pin ribbon cable used for IDE hard drives
- Diode and resistor protection is provided

2.3 Power-up the DE2 Board

The DE2 board comes with a preloaded configuration bit stream to demonstrate some features of the board. This bit stream also allows users to see quickly if the board is working properly. To power-up the board perform the following steps:

1. Connect the provided USB cable from the host computer to the USB Blaster connector on the DE2 board. For communication between the host and the DE2 board, it is necessary to install the Altera USB Blaster driver software. If this driver is not already installed on the host computer, it can be installed as explained in the tutorial *Getting Started with Altera's DE2 Board*. This tutorial is available on the **DE2 System CD-ROM** and from the Altera DE2 web pages.
2. Connect the 9V adapter to the DE2 board
3. Connect a VGA monitor to the VGA port on the DE2 board
4. Connect your headset to the Line-out audio port on the DE2 board
5. Turn the RUN/PROG switch on the left edge of the DE2 board to RUN position; the PROG position is used only for the AS Mode programming

6. Turn the power on by pressing the ON/OFF switch on the DE2 board

At this point you should observe the following:

- All user LEDs are flashing
- All 7-segment displays are cycling through the numbers 0 to F
- The LCD display shows **Welcome to the Altera DE2 Board**
- The VGA monitor displays the image shown in Figure 2.3.
- Set the toggle switch SW17 to the DOWN position; you should hear a 1-kHz sound
- Set the toggle switch SW17 to the UP position and connect the output of an audio player to the Line-in connector on the DE2 board; on your headset you should hear the music played from the audio player (MP3, PC, iPod, or the like)
- You can also connect a microphone to the Microphone-in connector on the DE2 board; your voice will be mixed with the music played from the audio player

Figure 2.3. The default VGA output pattern.

Chapter 3

DE2 Control Panel

The DE2 board comes with a Control Panel facility that allows a user to access various components on the board through a USB connection from a host computer. This chapter first presents some basic functions of the Control Panel, then describes its structure in block diagram form, and finally describes its capabilities.

3.1 Control Panel Setup

To run the Control Panel application, it is first necessary to configure a corresponding circuit in the Cyclone II FPGA. This is done by downloading the configuration file *DE2_USB_API.sof* into the FPGA. The downloading procedure is described in Section 4.1.

In addition to the *DE2_USB_API.sof* file, it is necessary to execute on the host computer the program *DE2_control_panel.exe*. Both of these files are available on the **DE2 System CD-ROM** that accompanies the DE2 board, in the directory *DE2_control_panel*. Of course, these files may already have been installed to some other location on your computer system.

To activate the Control Panel, perform the following steps:

1. Connect the supplied USB cable to the USB Blaster port, connect the 9V power supply, and turn the power switch ON
2. Set the RUN/PROG switch to the RUN position
3. Start the Quartus II software
4. Select **Tools > Programmer** to reach the window in Figure 3.1. Click on **Add File** and in the pop-up window that appears select the *DE2_USB_API.sof* file. Next, click on the **Program/Configure** box which results in the image displayed in the figure. Now, click **Start** to download the configuration file into the FPGA.
5. Start the executable *DE2_control_panel.exe* on the host computer. The Control Panel user interface shown in Figure 3.2 will appear.
6. Open the USB port by clicking **Open > Open USB Port 0**. The DE2 Control Panel application will list all the USB ports that connect to DE2 boards. The DE2 Control Panel can control up to 4 DE2 boards using the USB links. The Control Panel will occupy the USB port until you close that port; you cannot use Quartus II to download a configuration file into the FPGA until you close the USB port.

7. The Control Panel is now ready for use; experiment by setting the value of some 7-segment display and observing the result on the DE2 board.

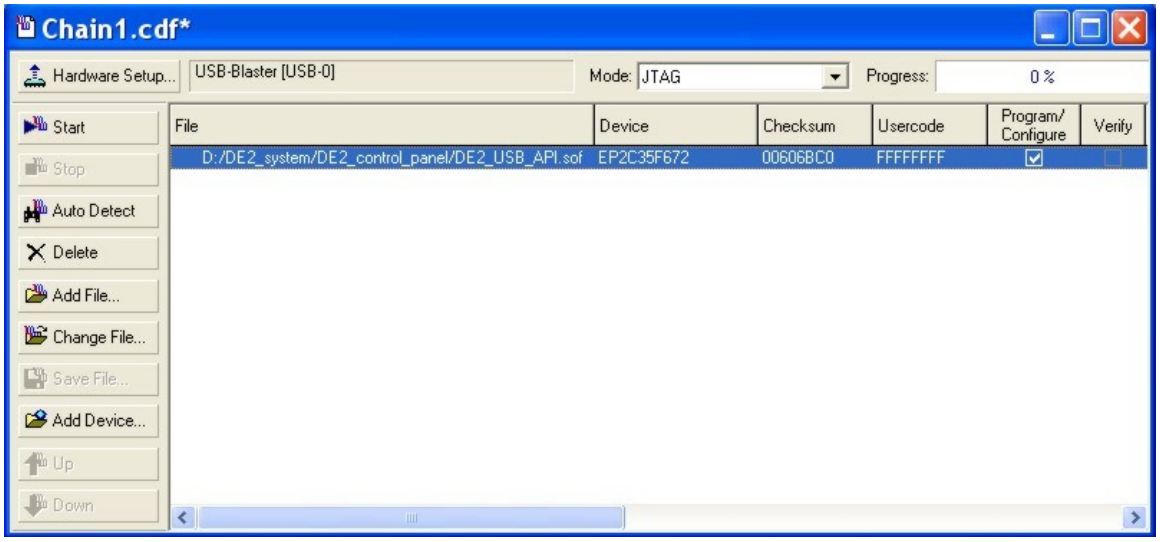

Figure 3.1. Quartus II Programmer window.

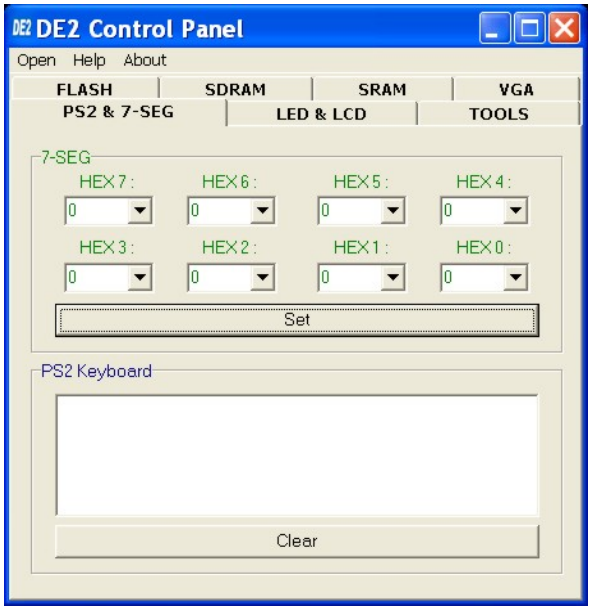

Figure 3.2. The DE2 Control Panel.

The concept of the DE2 Control Panel is illustrated in Figure 3.3. The IP that performs the control functions is implemented in the FPGA device. It communicates with the Control Panel window, which is active on the host computer, via the USB Blaster link. The graphical interface is used to issue commands to the control circuitry. The provided IP handles all requests and performs data transfers between the computer and the DE2 board.

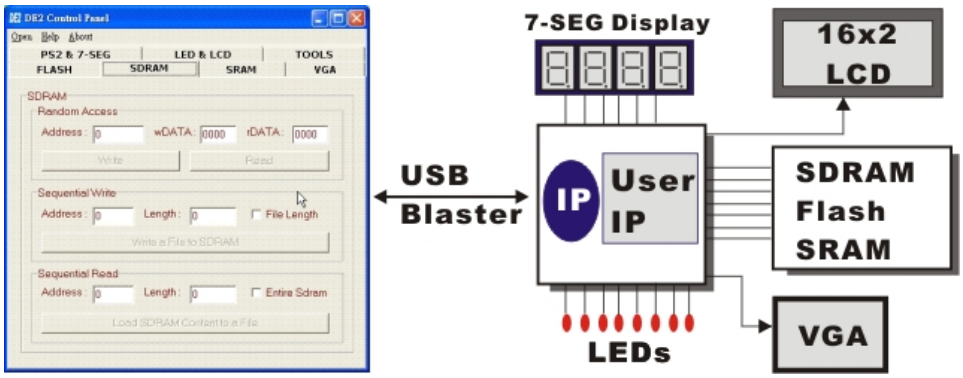

Figure 3.3. The DE2 Control Panel concept.

The DE2 Control Panel can be used to change the values displayed on 7-segment displays, light up LEDs, talk to the PS/2 keyboard, read/write the SRAM, Flash Memory and SDRAM, load an image pattern to display as VGA output, load music to the memory and play music via the audio DAC. The feature of reading/writing a byte or an entire file from/to the Flash Memory allows the user to develop multimedia applications (Flash Audio Player, Flash Picture Viewer) without worrying about how to build a Flash Memory Programmer.

3.2 Controlling the LEDs, 7-Segment Displays and LCD Display

A simple function of the Control Panel is to allow setting the values displayed on LEDs, 7-segment displays, and the LCD character display.

In the window shown in Figure 3.2, the values to be displayed by the 7-segment displays (which are named *HEX*7-0) can be entered into the corresponding boxes and displayed by pressing the **Set** button. A keyboard connected to the PS/2 port can be used to type text that will be displayed on the LCD display.

Choosing the **LED & LCD** tab leads to the window in Figure 3.4. Here, you can turn the individual LEDs on by selecting them and pressing the **Set** button. Text can be written to the LCD display by typing it in the LCD box and pressing the corresponding **Set** button.

The ability to set arbitrary values into simple display devices is not needed in typical design activities. However, it gives the user a simple mechanism for verifying that these devices are functioning correctly in case a malfunction is suspected. Thus, it can be used for troubleshooting purposes.

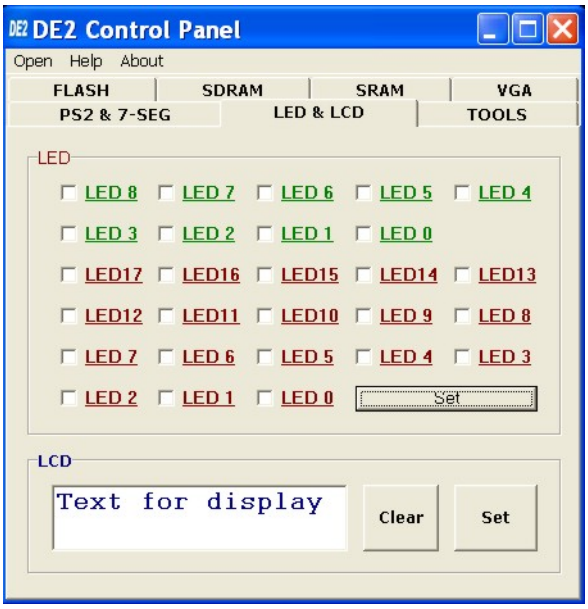
DE2 Control Panel
Open Help About
FLASH SDRAM SRAM VGA
PS2 & 7-SEG LED & LCD TOOLS
LED
LED 8 LED 7 LED 6 LED 5 LED 4
LED 3 LED 2 LED 1 LED 0
LED17 LED16 LED15 LED14 LED13
LED12 LED11 LED10 LED 9 LED 8
LED 7 LED 6 LED 5 LED 4 LED 3
LED 2 LED 1 LED 0 Set
LCD
Text for display
Clear
Set

Figure 3.4. Controlling LEDs and the LCD display.

3.3 SDRAM/SRAM Controller and Programmer

The Control Panel can be used to write/read data to/from the SDRAM and SRAM chips on the DE2 board. We will describe how the SDRAM may be accessed; the same approach is used to access the SRAM. Click on the SDRAM tab to reach the window in Figure 3.5.

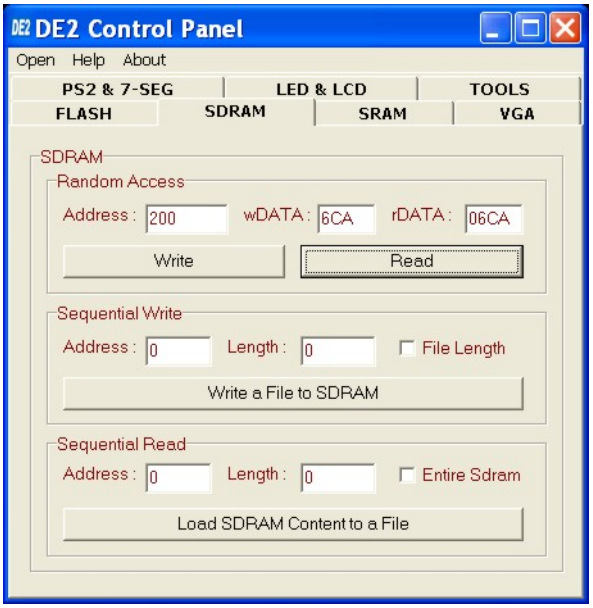
DE2 Control Panel
Open Help About
PS2 & 7-SEG LED & LCD TOOLS
FLASH SDRAM SRAM VGA
SDRAM
Random Access
Address : 200 wDATA : 6CA rDATA : 06CA
Write
Read
Sequential Write
Address : 0 Length : 0 File Length
Write a File to SDRAM
Sequential Read
Address : 0 Length : 0 Entire Sdram
Load SDRAM Content to a File

Figure 3.5. Accessing the SDRAM.

A 16-bit word can be written into the SDRAM by entering the address of the desired location, specifying the data to be written, and pressing the **Write** button. Contents of the location can be read by pressing the **Read** button. Figure 3.5 depicts the result of writing the hexadecimal value 6CA into location 200, followed by reading the same location.

The Sequential Write function of the Control Panel is used to write the contents of a file into the SDRAM as follows:

1. Specify the starting address in the **Address** box.
2. Specify the number of bytes to be written in the **Length** box. If the entire file is to be loaded, then a checkmark may be placed in the **File Length** box instead of giving the number of bytes.
3. To initiate the writing of data, click on the **Write a File to SDRAM** button.
4. When the Control Panel responds with the standard Windows dialog box asking for the source file, specify the desired file in the usual manner.

The Control Panel also supports loading files with a *.hex* extension. Files with a *.hex* extension are ASCII text files that specify memory values using ASCII characters to represent hexadecimal values. For example, a file containing the line

0123456789ABCDEF

defines four 16-bit values: 0123, 4567, 89AB, CDEF. These values will be loaded consecutively into the memory.

The Sequential Read function is used to read the contents of the SDRAM and place them into a file as follows:

1. Specify the starting address in the **Address** box.
2. Specify the number of bytes to be copied into the file in the **Length** box. If the entire contents of the SDRAM are to be copied (which involves all 8 Mbytes), then place a checkmark in the **Entire SDRAM** box.
3. Press **Load SDRAM Content to a File** button.
4. When the Control Panel responds with the standard Windows dialog box asking for the destination file, specify the desired file in the usual manner.

3.4 Flash Memory Programmer

The Control Panel can be used to write/read data to/from the Flash memory chip on the DE2 board. It can be used to:

- Erase the entire Flash memory
- Write one byte to the memory
- Read one byte from the memory
- Write a binary file to the memory
- Load the contents of the Flash memory into a file

Note the following characteristics of the Flash memory:

- The Flash memory chip is organized as 4 M (or 1 M on some boards) x 8 bits.
- You must erase the entire Flash memory before you can write into it. (Be aware that the number of times a Flash memory can be erased is limited.)
- The time required to erase the entire Flash memory is about 20 seconds. Do not close the DE2 Control Panel in the middle of the operation.

To open the Flash memory control window, shown in Figure 3.6, select the FLASH tab in the Control Panel.

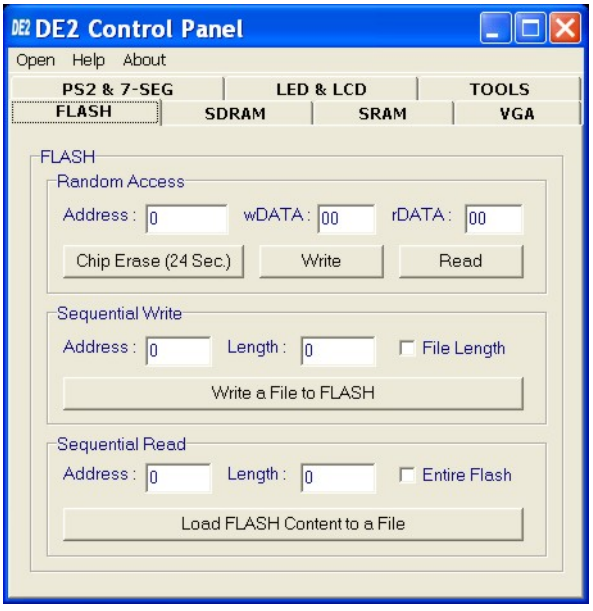

Figure 3.6. Flash memory control window.

A byte of data can be written into a random location on the Flash chip as follows:

1. Click on the **Chip Erase** button. The button and the window frame title will prompt you to wait until the operation is finished, which takes about 20 seconds.

2. Enter the desired address into the **Address** box and the data byte into the **wDATA** box. Then, click on the **Write** button.

To read a byte of data from a random location, enter the address of the location and click on the **Read** button. The **rDATA** box will display the data read back from the address specified.

The Sequential Write function is used to load a file into the Flash chip as follows:

1. Specify the starting address and the length of data (in bytes) to be written into the Flash memory. You can click on the **File Length** checkbox to indicate that you want to load the entire file.
2. Click on the **Write a File to Flash** button to activate the writing process.
3. When the Control Panel responds with the standard Windows dialog box asking for the source file, specify the desired file in the usual manner.

The Sequential Read function is used to read the data stored in the Flash memory and write this data into a file as follows:

1. Specify the starting address and the length of data (in bytes) to be read from the Flash memory. You can click on the **Entire Flash** checkbox to indicate that you want to copy the entire contents of the Flash memory into a specified file.
2. Click on the **Load Flash Content to a File** button to activate the reading process.
3. When the Control Panel responds with the standard Windows dialog box asking for the destination file, specify the desired file in the usual manner.

3.5 Overall Structure of the DE2 Control Panel

The DE2 Control Panel facility communicates with a circuit that is instantiated in the Cyclone II FPGA. This circuit is specified in Verilog code, which makes it possible for a knowledgeable user to change the functionality of the Control Panel. The code is located inside the *DE2_demonstrations* directory on the **DE2 System CD-ROM**.

To run the Control Panel, the user must first set it up as explained in Section 3.1. Figure 3.7 depicts the structure of the Control Panel. Each input/output device is controlled by a controller instantiated in the FPGA chip. The communication with the PC is done via the USB Blaster link. A Command Controller circuit interprets the commands received from the PC and performs the appropriate actions. The SDRAM, SRAM, and Flash Memory controllers have three user-selectable asynchronous ports in addition to the Host port that provides a link with the Command Controller. The connection between the VGA DAC Controller and the FPGA memory allows displaying of the default image shown on the left side of the figure, which is stored in an M4K block in the Cyclone

II chip. The connection between the Audio DAC Controller and a lookup table in the FPGA is used to produce a test audio signal of 1 kHz.

To let users implement and test their IP cores (written in Verilog) without requiring them to implement complex API/Host control software and memory (SRAM/SDRAM/Flash) controllers, we provide an integrated control environment consisting of a software controller in C++, a USB command controller, and a multi-port SRAM/SDRAM/Flash controller.

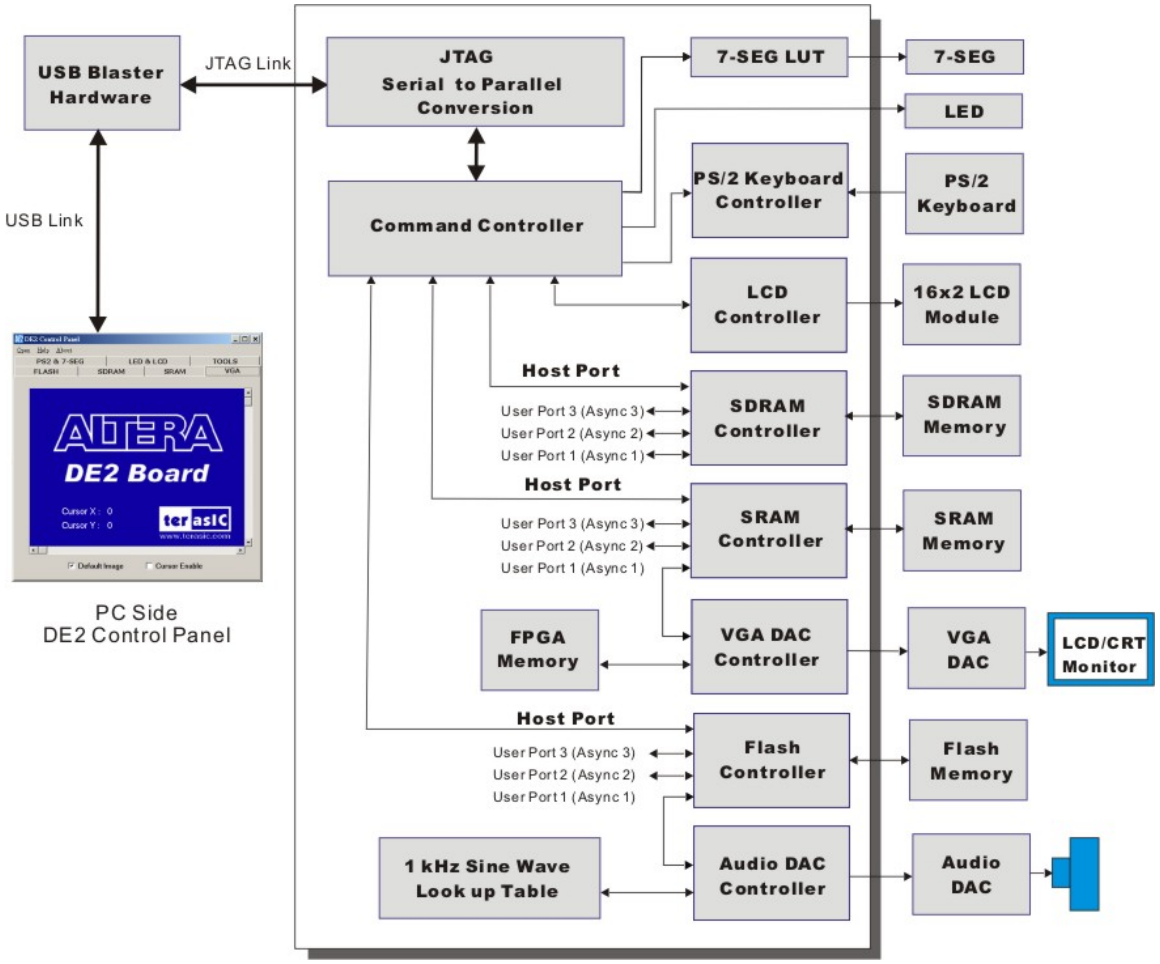

Figure 3.7. The DE2 Control Panel block diagram.

Users can connect circuits of their own design to one of the User Ports of the SRAM/SDRAM/Flash controller. Then, they can download binary data into the SRAM/SDRAM/Flash. Once the data is downloaded to the SDRAM/Flash, users can configure the memory controllers so that their circuits can read/write the SDRAM/Flash via the User Ports connected.

3.6 TOOLS – Multi-Port SRAM/SDRAM/Flash Controller

The TOOLS page of the Control Panel GUI allows selection of the User Ports. We will illustrate a typical process by implementing a Flash Music Player. The music data is loaded into the Flash memory. User Port 1 in the Flash Controller is used to send the music data to the Audio DAC Controller and hence to the audio output jack.

You can implement this application as follows:

1. Erase the Flash memory (as explained in Section 3.4). Then, write a music file into the Flash memory. You can use the file *music.wav* in the directory *DE2_demonstrations\music* on the **DE2 System CD-ROM**.
2. In the DE2 Control Panel, select the TOOLS tab to reach the window in Figure 3.8.

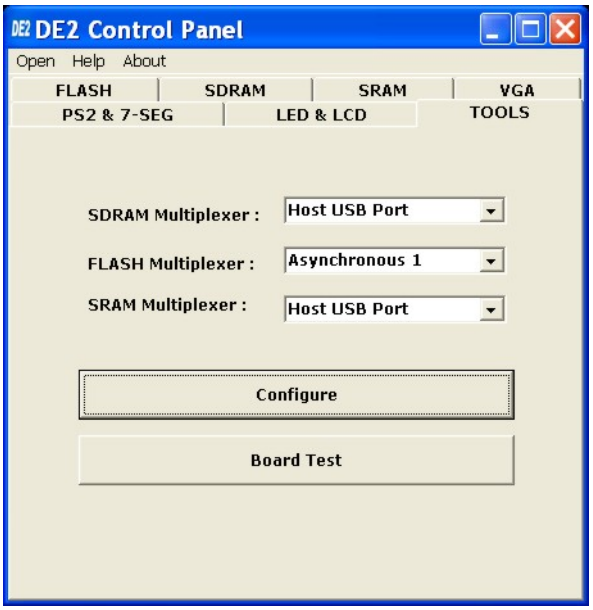

Figure 3.8. TOOLS window of the DE2 Control Panel.

3. Select the Asynchronous 1 port for the Flash Multiplexer and then click on the **Configure** button to activate the port. You need to click the Configure button to enable the connection from the Flash Memory to the Asynchronous Port 1 of the Flash Controller (indicated in Figure 3.7).
4. Set toggle switches SW1 and SW0 to OFF (DOWN position) and ON (UP position), respectively.
5. Plug your headset or a speaker into the audio output jack and you should hear the music played from the Audio DAC circuit.
6. Note that the Asynchronous Port 1 is connected to the Audio DAC part, as shown in Figure 3.7. Once you selected Asynchronous Port 1 and clicked the Configure button, the Audio DAC Controller will communicate with the Flash memory directly. In our example, the

AUDIO_DAC Verilog module defines a circuit that reads the contents of the Flash memory and sends it to the external audio chip.

3.7 VGA Display Control

The Control Panel provides a tool with the associated IP that allows the user to display an image via the VGA output port. To illustrate this feature, we will show how an image can be displayed on a VGA monitor. Perform the following steps to display a default image:

- Select the VGA tab in the Control Panel to reach the window in Figure 3.9.

Figure 3.9. Displayed image and the cursor controlled by the scroll bars

- Make sure that the checkboxes **Default Image** and **Cursor Enable** are checked.
- Connect a VGA monitor to the DE2 board and you should see on the screen the default image shown in Figure 3.9. The image includes a cursor which can be controlled by means of the X/Y-axes scroll bars on the DE2 Control Panel.

The image in Figure 3.9 is stored in an M4K memory block in the Cyclone II FPGA. It is loaded into the M4K block in the MIF/Hex(Intel) format during the default bit stream configuration stage. We will next describe how you can display other images and use your own images to generate the binary data patterns that can be displayed on the VGA monitor.

Another image is provided in the file *picture.dat* in the folder *DE2_demonstrations\pictures* on the **DE2 System CD-ROM**. You can display this image as follows:

- Select the **SRAM** page of the Control Panel and load the file *picture.dat* into the SRAM.

- Select the **TOOLS** page and choose **Asynchronous 1** for the **SRAM multiplexer** port as shown in Figure 3.10. Click on the **Configure** button to activate the multi-port setup.

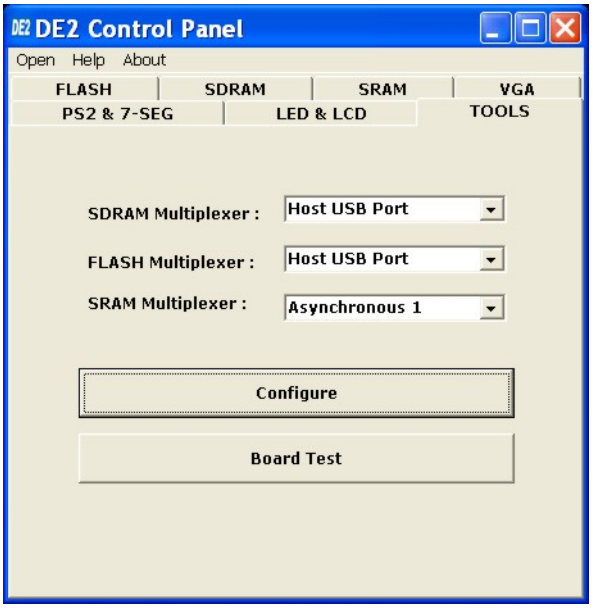

Figure 3.10. Use the Asynchronous Port 1 to access the image data in the SRAM.

- The FPGA is now configured as indicated in Figure 3.11.
- Select the **VGA** page and deselect the checkbox **Default Image**.
- The VGA monitor should display the *picture.dat* image from the SRAM, as depicted in Figure 3.12. You can turn off the cursor by deselecting the **Cursor Enable** checkbox.

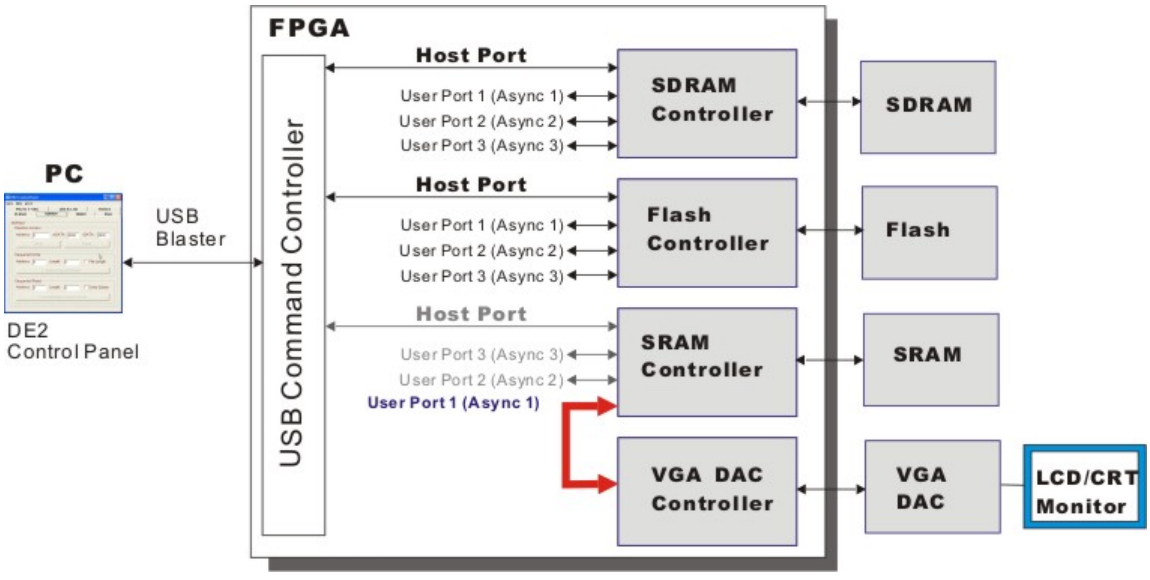

Figure 3.11. Multi-Port Controller configured to display an image from the SRAM.

Figure 3.12. A displayed image.

You can display any image file by loading it into the SRAM chip or into an M4K memory block in the Cyclone II chip. This requires generating a bitmap file, which may be done as follows:

1. Load the desired image into an image processing tool, such as Corel PhotoPaint.
2. Resample the original image to have a 640 x 480 resolution. Save the modified image in the Windows Bitmap format.
3. Execute *DE2_control_panel\ImgConv.exe*, an image conversion tool developed for the DE2 board, to reach the window in Figure 3.13.
4. Click on the **Open Bitmap** button and select the 640 x 480 Grayscale photo for conversion.
5. When the processing of the file is completed, click on the **Save Raw Data** button and a file named *Raw_Data_Gray.dat* will be generated and stored in the same directory as the original image file. You can change the file name prefix from *Raw_Data* to another name by changing the File Name field in the displayed window.
6. *Raw_Data_Gray.dat* is the raw data that can be downloaded directly into the SRAM on the DE2 board and displayed on the VGA monitor using the VGA controller IP described in the *DE2_USB_API* project.
7. The *ImgConv* tool will also generate *Raw_Data_BW.dat* (and its corresponding TXT format) for the black and white version of the image – the threshold for judging black or white level is defined in the BW Threshold.

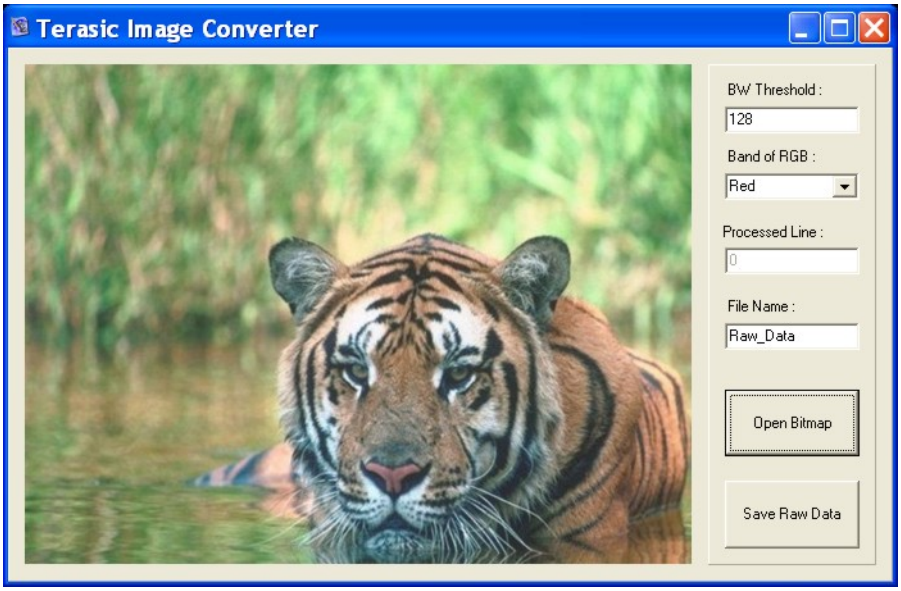

Figure 3.13. The image converter window.

Image Source	R/G/B Band Filter	B&W Threshold Filter	Output Result (640x480)
Color Picture	R/G/B	N/A	Raw_Data_Gray
Color Picture	R/G/B (optional)	BW Threshold	Raw_Data_BW + Raw_Data_BW.txt
Grayscale Picture	N/A	N/A	Raw_Data_Gray
Grayscale Picture	N/A	BW Threshold	Raw_Data_BW + Raw_Data_BW.txt

Note: Raw_Data_BW.txt is used to fill in the MIF/Intel Hex format for M4K SRAM

Chapter 4
Using the DE2 Board

This chapter gives instructions for using the DE2 board and describes each of its I/O devices.

4.1 Configuring the Cyclone II FPGA

The procedure for downloading a circuit from a host computer to the DE2 board is described in the tutorial *Quartus II Introduction*. This tutorial is found in the *DE2_tutorials* folder on the **DE2 System CD-ROM,** and it is also available on the Altera DE2 web pages. The user is encouraged to read the tutorial first, and to treat the information below as a short reference.

The DE2 board contains a serial EEPROM chip that stores configuration data for the Cyclone II FPGA. This configuration data is automatically loaded from the EEPROM chip into the FPGA each time power is applied to the board. Using the Quartus II software, it is possible to reprogram the FPGA at any time, and it is also possible to change the non-volatile data that is stored in the serial EEPROM chip. Both types of programming methods are described below.

1. *JTAG* programming: In this method of programming, named after the IEEE standards *Joint Test Action Group*, the configuration bit stream is downloaded directly into the Cyclone II FPGA. The FPGA will retain this configuration as long as power is applied to the board; the configuration is lost when the power is turned off.
2. *AS* programming: In this method, called *Active Serial* programming, the configuration bit stream is downloaded into the Altera EPCS16 serial EEPROM chip. It provides non-volatile storage of the bit stream, so that the information is retained even when the power supply to the DE2 board is turned off. When the board's power is turned on, the configuration data in the EPCS16 device is automatically loaded into the Cyclone II FPGA.

The sections below describe the steps used to perform both JTAG and AS programming. For both methods the DE2 board is connected to a host computer via a USB cable. Using this connection, the board will be identified by the host computer as an Altera *USB Blaster* device. The process for installing on the host computer the necessary software device driver that communicates with the USB Blaster is described in the tutorial *Getting Started with Altera's DE2 Board*. This tutorial is available on the **DE2 System CD-ROM** and from the Altera DE2 web pages.

Configuring the FPGA in JTAG Mode

Figure 4.1 illustrates the JTAG configuration setup. To download a configuration bit stream into the Cyclone II FPGA, perform the following steps:

- Ensure that power is applied to the DE2 board
- Connect the supplied USB cable to the USB Blaster port on the DE2 board (see Figure 2.1)
- Configure the JTAG programming circuit by setting the RUN/PROG switch (on the left side of the board) to the RUN position.
- The FPGA can now be programmed by using the Quartus II Programmer module to select a configuration bit stream file with the *.sof* filename extension

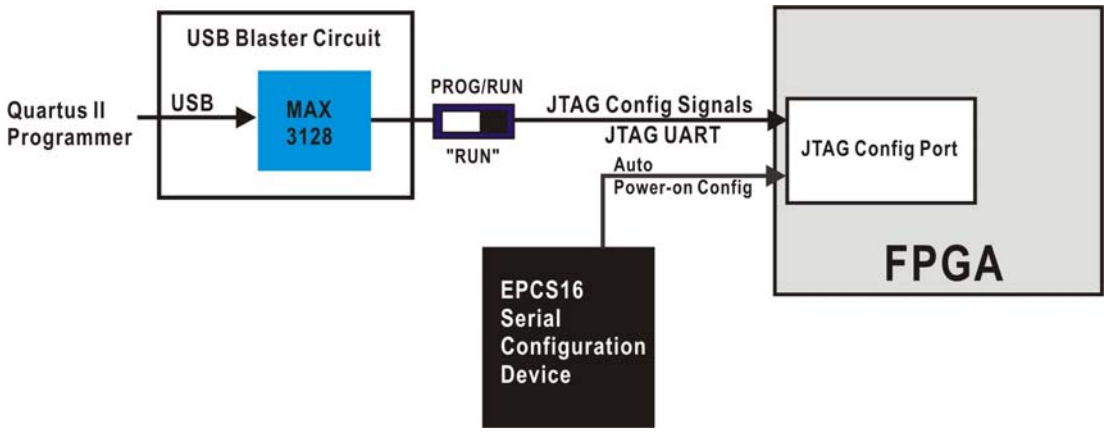

Figure 4.1. The JTAG configuration scheme.

Configuring the EPCS16 in AS Mode

Figure 4.2 illustrates the AS configuration set up. To download a configuration bit stream into the EPCS16 serial EEPROM device, perform the following steps:

- Ensure that power is applied to the DE2 board
- Connect the supplied USB cable to the USB Blaster port on the DE2 board (see Figure 2.1)
- Configure the JTAG programming circuit by setting the RUN/PROG switch (on the left side of the board) to the PROG position.
- The EPCS16 chip can now be programmed by using the Quartus II Programmer module to select a configuration bit stream file with the *.pof* filename extension
- Once the programming operation is finished, set the RUN/PROG switch back to the RUN position and then reset the board by turning the power switch off and back on; this action causes the new configuration data in the EPCS16 device to be loaded into the FPGA chip.

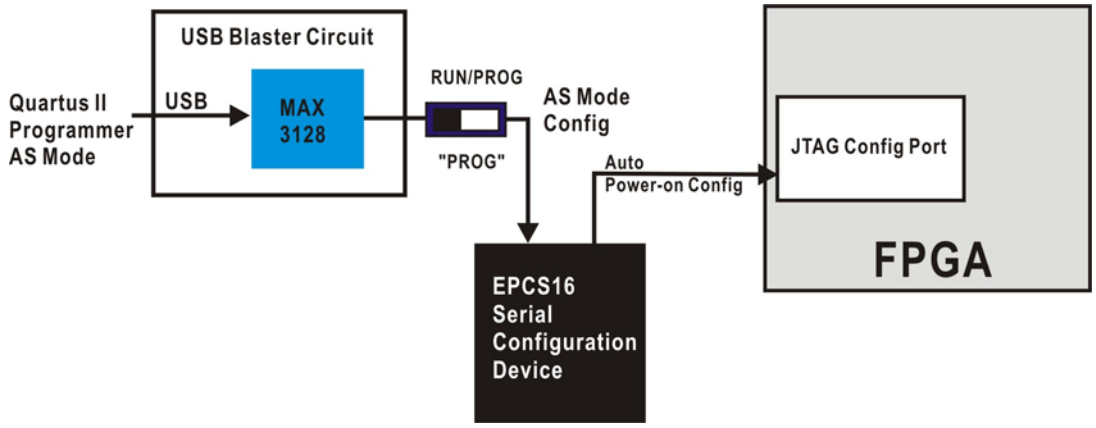

Figure 4.2. The AS configuration scheme.

In addition to its use for JTAG and AS programming, the USB Blaster port on the DE2 board can also be used to control some of the board's features remotely from a host computer. Details that describe this method of using the USB Blaster port are given in Chapter 3.

4.2 Using the LEDs and Switches

The DE2 board provides four pushbutton switches. Each of these switches is debounced using a Schmitt Trigger circuit, as indicated in Figure 4.3. The four outputs called *KEY0*, …, *KEY3* of the Schmitt Trigger device are connected directly to the Cyclone II FPGA. Each switch provides a high logic level (3.3 volts) when it is not pressed, and provides a low logic level (0 volts) when depressed. Since the pushbutton switches are debounced, they are appropriate for use as clock or reset inputs in a circuit.

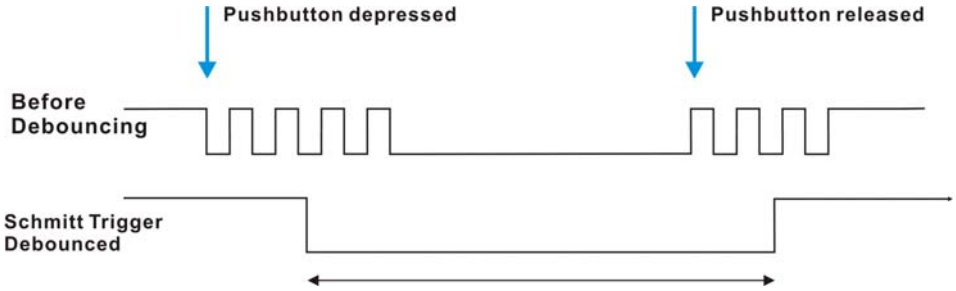

Figure 4.3. Switch debouncing.

There are also 18 toggle switches (sliders) on the DE2 board. These switches are not debounced, and are intended for use as level-sensitive data inputs to a circuit. Each switch is connected directly to a pin on the Cyclone II FPGA. When a switch is in the DOWN position (closest to the edge of the board) it provides a low logic level (0 volts) to the FPGA, and when the switch is in the UP position it provides a high logic level (3.3 volts).

There are 27 user-controllable LEDs on the DE2 board. Eighteen red LEDs are situated above the 18 toggle switches, and eight green LEDs are found above the pushbutton switches (the 9th green LED is in the middle of the 7-segment displays). Each LED is driven directly by a pin on the Cyclone II FPGA; driving its associated pin to a high logic level turns the LED on, and driving the pin low turns it off. A schematic diagram that shows the pushbutton and toggle switches is given in Figure 4.4. A schematic diagram that shows the LED circuitry appears in Figure 4.5.

A list of the pin names on the Cyclone II FPGA that are connected to the toggle switches is given in Table 4.1. Similarly, the pins used to connect to the pushbutton switches and LEDs are displayed in Tables 4.2 and 4.3, respectively.

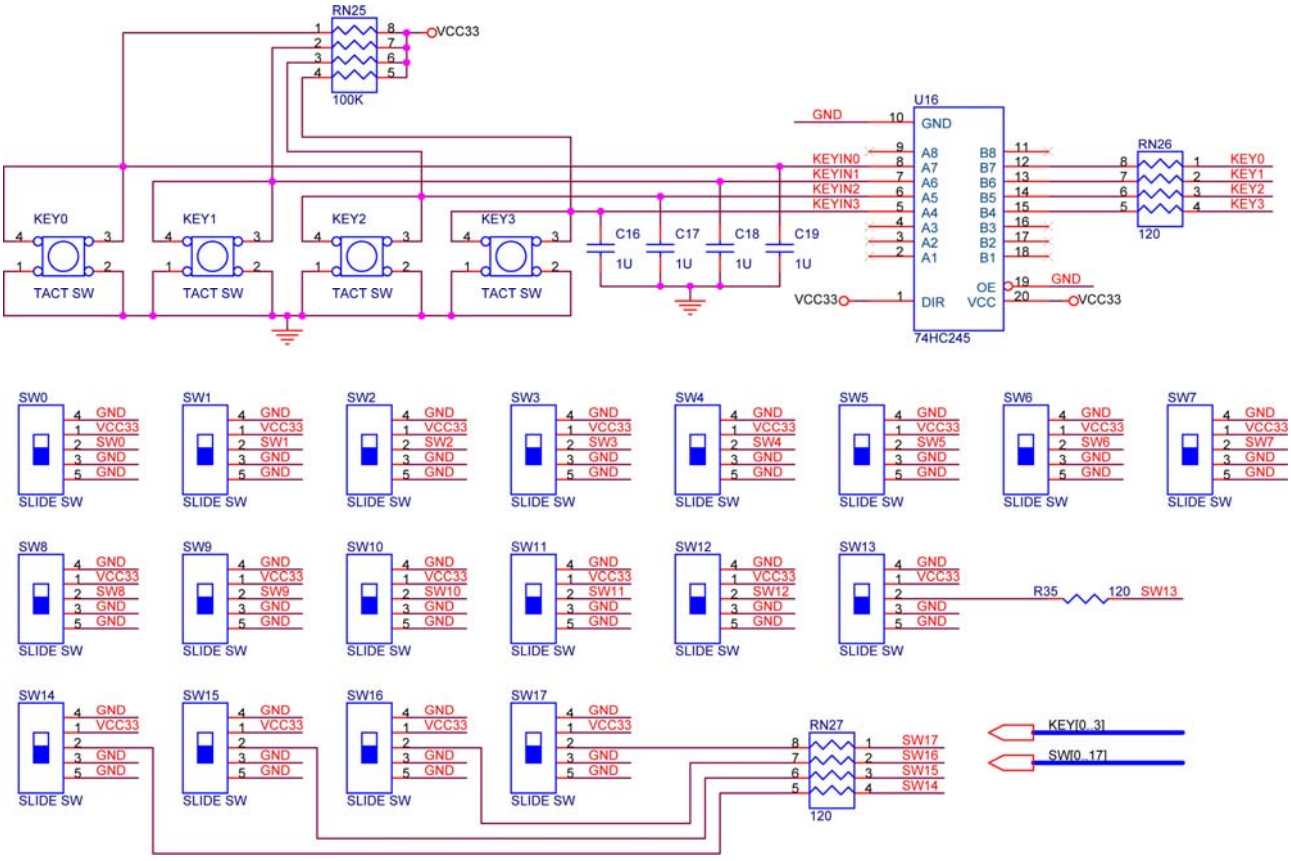

Figure 4.4. Schematic diagram of the pushbutton and toggle switches.

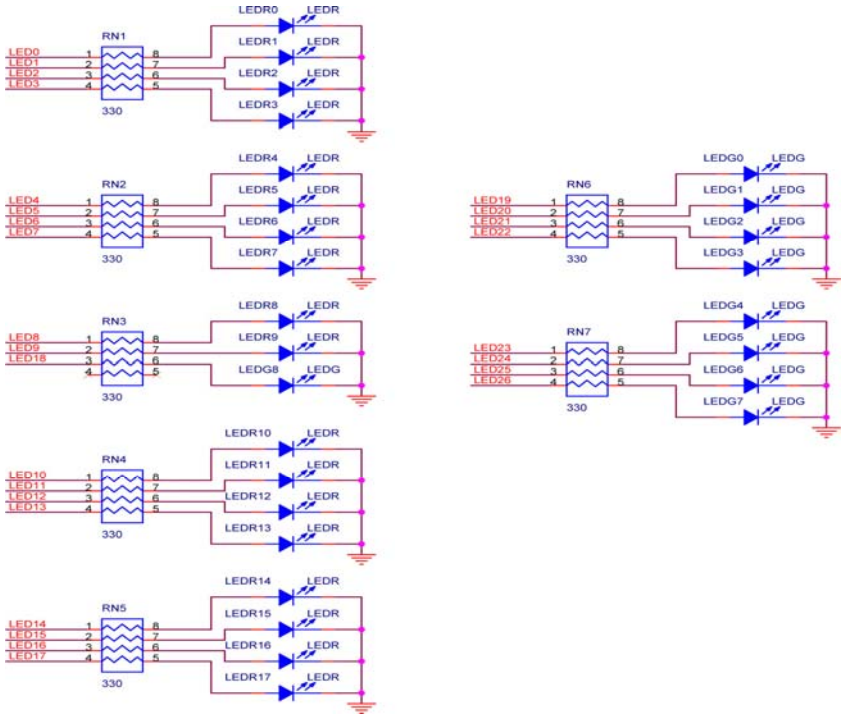

Figure 4.5. Schematic diagram of the LEDs.

Signal Name	FPGA Pin No.	Description
SW[0]	PIN_N25	Toggle Switch[0]
SW[1]	PIN_N26	Toggle Switch[1]
SW[2]	PIN_P25	Toggle Switch[2]
SW[3]	PIN_AE14	Toggle Switch[3]
SW[4]	PIN_AF14	Toggle Switch[4]
SW[5]	PIN_AD13	Toggle Switch[5]
SW[6]	PIN_AC13	Toggle Switch[6]
SW[7]	PIN_C13	Toggle Switch[7]
SW[8]	PIN_B13	Toggle Switch[8]
SW[9]	PIN_A13	Toggle Switch[9]
SW[10]	PIN_N1	Toggle Switch[10]
SW[11]	PIN_P1	Toggle Switch[11]
SW[12]	PIN_P2	Toggle Switch[12]
SW[13]	PIN_T7	Toggle Switch[13]
SW[14]	PIN_U3	Toggle Switch[14]
SW[15]	PIN_U4	Toggle Switch[15]
SW[16]	PIN_V1	Toggle Switch[16]
SW[17]	PIN_V2	Toggle Switch[17]

Table 4.1. Pin assignments for the toggle switches.

Signal Name	FPGA Pin No.	Description
KEY[0]	PIN_G26	Pushbutton[0]
KEY[1]	PIN_N23	Pushbutton[1]
KEY[2]	PIN_P23	Pushbutton[2]
KEY[3]	PIN_W26	Pushbutton[3]

Table 4.2. Pin assignments for the pushbutton switches.

Signal Name	FPGA Pin No.	Description
LEDR[0]	PIN_AE23	LED Red[0]
LEDR[1]	PIN_AF23	LED Red[1]
LEDR[2]	PIN_AB21	LED Red[2]
LEDR[3]	PIN_AC22	LED Red[3]
LEDR[4]	PIN_AD22	LED Red[4]
LEDR[5]	PIN_AD23	LED Red[5]
LEDR[6]	PIN_AD21	LED Red[6]
LEDR[7]	PIN_AC21	LED Red[7]
LEDR[8]	PIN_AA14	LED Red[8]
LEDR[9]	PIN_Y13	LED Red[9]
LEDR[10]	PIN_AA13	LED Red[10]
LEDR[11]	PIN_AC14	LED Red[11]
LEDR[12]	PIN_AD15	LED Red[12]
LEDR[13]	PIN_AE15	LED Red[13]
LEDR[14]	PIN_AF13	LED Red[14]
LEDR[15]	PIN_AE13	LED Red[15]
LEDR[16]	PIN_AE12	LED Red[16]
LEDR[17]	PIN_AD12	LED Red[17]
LEDG[0]	PIN_AE22	LED Green[0]
LEDG[1]	PIN_AF22	LED Green[1]
LEDG[2]	PIN_W19	LED Green[2]
LEDG[3]	PIN_V18	LED Green[3]
LEDG[4]	PIN_U18	LED Green[4]
LEDG[5]	PIN_U17	LED Green[5]
LEDG[6]	PIN_AA20	LED Green[6]
LEDG[7]	PIN_Y18	LED Green[7]
LEDG[8]	PIN_Y12	LED Green[8]

Table 4.3. Pin assignments for the LEDs.

4.3 Using the 7-segment Displays

The DE2 Board has eight 7-segment displays. These displays are arranged into two pairs and a group of four, with the intent of displaying numbers of various sizes. As indicated in the schematic in Figure 4.6, the seven segments are connected to pins on the Cyclone II FPGA. Applying a low logic level to a segment causes it to light up, and applying a high logic level turns it off.

Each segment in a display is identified by an index from 0 to 6, with the positions given in Figure 4.7. Note that the dot in each display is unconnected and cannot be used. Table 4.4 shows the assignments of FPGA pins to the 7-segment displays.

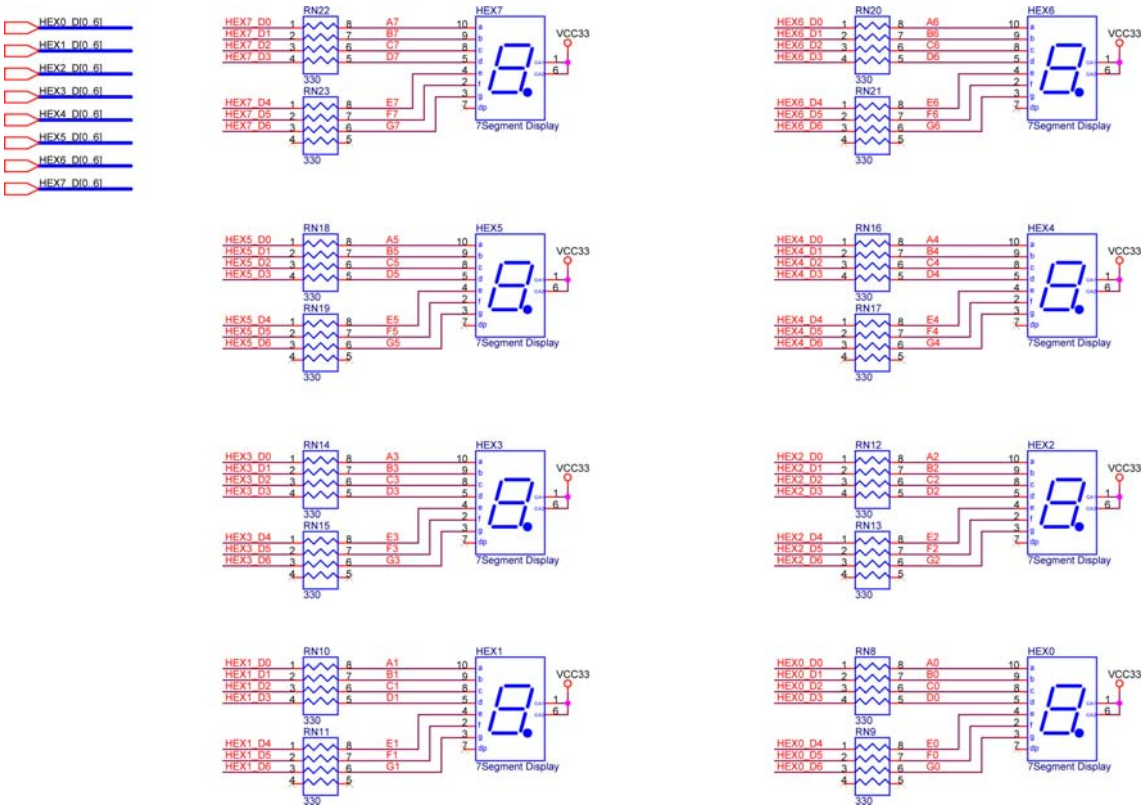

Figure 4.6. Schematic diagram of the 7-segment displays.

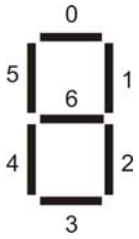

Figure 4.7. Position and index of each segment in a 7-segment display.

Signal Name	FPGA Pin No.	Description
HEX0[0]	PIN_AF10	Seven Segment Digit 0[0]
HEX0[1]	PIN_AB12	Seven Segment Digit 0[1]
HEX0[2]	PIN_AC12	Seven Segment Digit 0[2]
HEX0[3]	PIN_AD11	Seven Segment Digit 0[3]
HEX0[4]	PIN_AE11	Seven Segment Digit 0[4]
HEX0[5]	PIN_V14	Seven Segment Digit 0[5]
HEX0[6]	PIN_V13	Seven Segment Digit 0[6]
HEX1[0]	PIN_V20	Seven Segment Digit 1[0]
HEX1[1]	PIN_V21	Seven Segment Digit 1[1]
HEX1[2]	PIN_W21	Seven Segment Digit 1[2]
HEX1[3]	PIN_Y22	Seven Segment Digit 1[3]
HEX1[4]	PIN_AA24	Seven Segment Digit 1[4]
HEX1[5]	PIN_AA23	Seven Segment Digit 1[5]
HEX1[6]	PIN_AB24	Seven Segment Digit 1[6]
HEX2[0]	PIN_AB23	Seven Segment Digit 2[0]
HEX2[1]	PIN_V22	Seven Segment Digit 2[1]
HEX2[2]	PIN_AC25	Seven Segment Digit 2[2]
HEX2[3]	PIN_AC26	Seven Segment Digit 2[3]
HEX2[4]	PIN_AB26	Seven Segment Digit 2[4]
HEX2[5]	PIN_AB25	Seven Segment Digit 2[5]
HEX2[6]	PIN_Y24	Seven Segment Digit 2[6]
HEX3[0]	PIN_Y23	Seven Segment Digit 3[0]
HEX3[1]	PIN_AA25	Seven Segment Digit 3[1]
HEX3[2]	PIN_AA26	Seven Segment Digit 3[2]
HEX3[3]	PIN_Y26	Seven Segment Digit 3[3]
HEX3[4]	PIN_Y25	Seven Segment Digit 3[4]
HEX3[5]	PIN_U22	Seven Segment Digit 3[5]
HEX3[6]	PIN_W24	Seven Segment Digit 3[6]
HEX4[0]	PIN_U9	Seven Segment Digit 4[0]
HEX4[1]	PIN_U1	Seven Segment Digit 4[1]
HEX4[2]	PIN_U2	Seven Segment Digit 4[2]
HEX4[3]	PIN_T4	Seven Segment Digit 4[3]
HEX4[4]	PIN_R7	Seven Segment Digit 4[4]
HEX4[5]	PIN_R6	Seven Segment Digit 4[5]
HEX4[6]	PIN_T3	Seven Segment Digit 4[6]
HEX5[0]	PIN_T2	Seven Segment Digit 5[0]

HEX5[1]	PIN_P6	Seven Segment Digit 5[1]
HEX5[2]	PIN_P7	Seven Segment Digit 5[2]
HEX5[3]	PIN_T9	Seven Segment Digit 5[3]
HEX5[4]	PIN_R5	Seven Segment Digit 5[4]
HEX5[5]	PIN_R4	Seven Segment Digit 5[5]
HEX5[6]	PIN_R3	Seven Segment Digit 5[6]
HEX6[0]	PIN_R2	Seven Segment Digit 6[0]
HEX6[1]	PIN_P4	Seven Segment Digit 6[1]
HEX6[2]	PIN_P3	Seven Segment Digit 6[2]
HEX6[3]	PIN_M2	Seven Segment Digit 6[3]
HEX6[4]	PIN_M3	Seven Segment Digit 6[4]
HEX6[5]	PIN_M5	Seven Segment Digit 6[5]
HEX6[6]	PIN_M4	Seven Segment Digit 6[6]
HEX7[0]	PIN_L3	Seven Segment Digit 7[0]
HEX7[1]	PIN_L2	Seven Segment Digit 7[1]
HEX7[2]	PIN_L9	Seven Segment Digit 7[2]
HEX7[3]	PIN_L6	Seven Segment Digit 7[3]
HEX7[4]	PIN_L7	Seven Segment Digit 7[4]
HEX7[5]	PIN_P9	Seven Segment Digit 7[5]
HEX7[6]	PIN_N9	Seven Segment Digit 7[6]

Table 4.4. Pin assignments for the 7-segment displays.

4.4 Clock Inputs

The DE2 board includes two oscillators that produce 27 MHz and 50 MHz clock signals. The board also includes an SMA connector which can be used to connect an external clock source to the board. The schematic of the clock circuitry is shown in Figure 4.8, and the associated pin assignments appear in Table 4.5.

The 27-MHz clock is fed to the FPGA from the TV decoder chip. The chip has an active-low reset signal that inhibits the clock when it is asserted to a low-logic level. To get the 27-MHz clock to appear on the input pin, the TV decoder chip's reset signal (TD_RESET, PIN_C4 on the FPGA) must be asserted to a high-logic level.

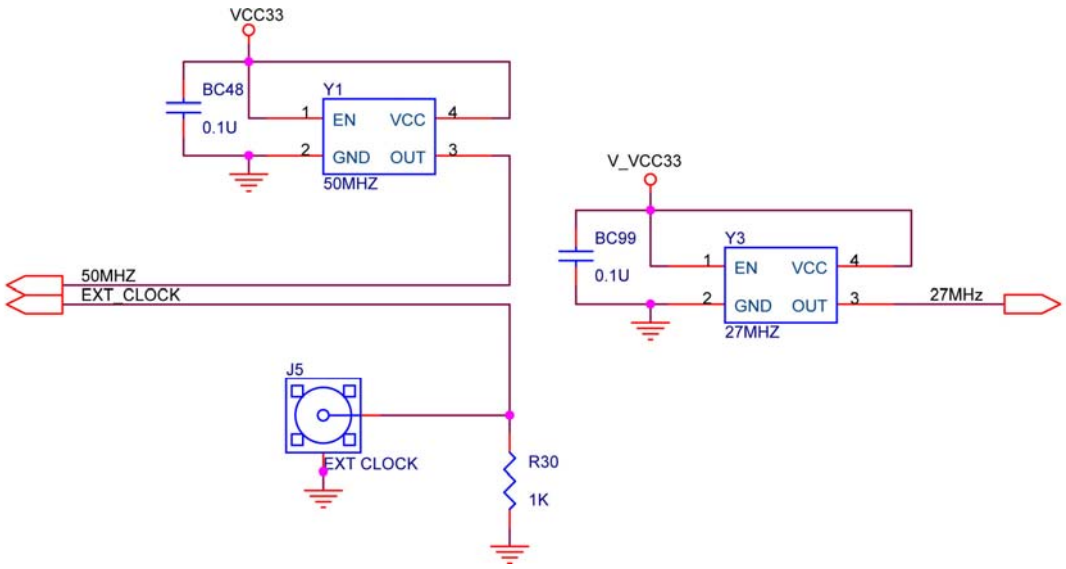

Figure 4.8. Schematic diagram of the clock circuit.

Signal Name	FPGA Pin No.	Description
CLOCK_27	PIN_D13	27 MHz clock input
CLOCK_50	PIN_N2	50 MHz clock input
EXT_CLOCK	PIN_P26	External (SMA) clock input

Table 4.5. Pin assignments for the clock inputs.

4.5 Using the LCD Module

The LCD module has built-in fonts and can be used to display text by sending appropriate commands to the display controller, which is called HD44780. Detailed information for using the display is available in its datasheet, which can be found on the manufacturer's web site, and from the *Datasheet* folder on the **DE2 System CD-ROM**. A schematic diagram of the LCD module showing connections to the Cyclone II FPGA is given in Figure 4.9. The associated pin assignments appear in Table 4.6.

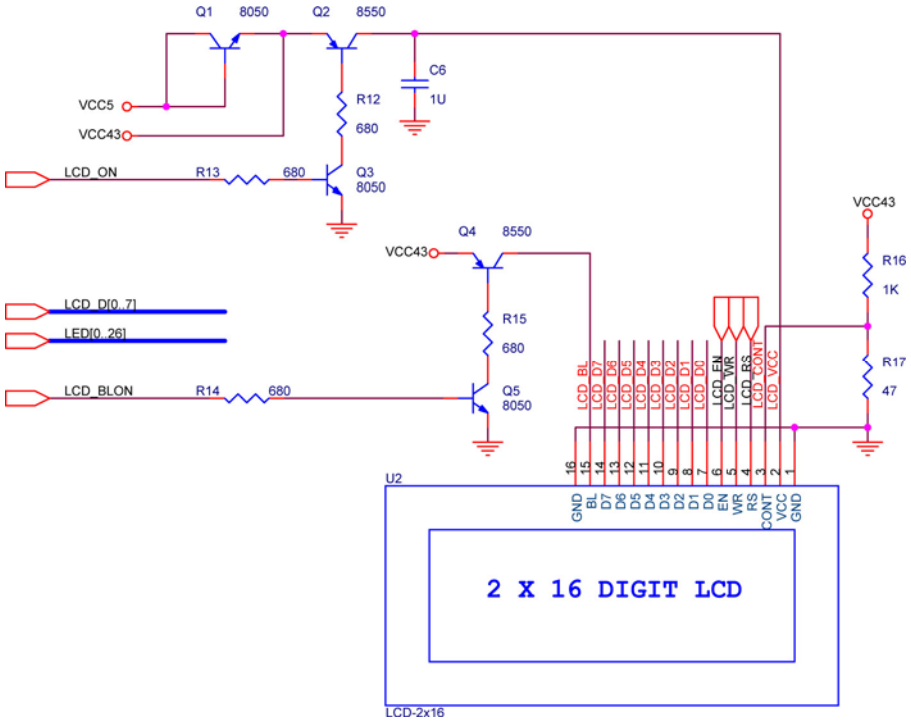

Figure 4.9. Schematic diagram of the LCD module.

Signal Name	FPGA Pin No.	Description
LCD_DATA[0]	PIN_J1	LCD Data[0]
LCD_DATA[1]	PIN_J2	LCD Data[1]
LCD_DATA[2]	PIN_H1	LCD Data[2]
LCD_DATA[3]	PIN_H2	LCD Data[3]
LCD_DATA[4]	PIN_J4	LCD Data[4]
LCD_DATA[5]	PIN_J3	LCD Data[5]
LCD_DATA[6]	PIN_H4	LCD Data[6]
LCD_DATA[7]	PIN_H3	LCD Data[7]
LCD_RW	PIN_K4	LCD Read/Write Select, 0 = Write, 1 = Read
LCD_EN	PIN_K3	LCD Enable
LCD_RS	PIN_K1	LCD Command/Data Select, 0 = Command, 1 = Data
LCD_ON	PIN_L4	LCD Power ON/OFF
LCD_BLON	PIN_K2	LCD Back Light ON/OFF

Table 4.6. Pin assignments for the LCD module.

4.6 Using the Expansion Header

The DE2 Board provides two 40-pin expansion headers. Each header connects directly to 36 pins on the Cyclone II FPGA, and also provides DC +5V (VCC5), DC +3.3V (VCC33), and two GND pins. Figure 4.10 shows the related schematics. Each pin on the expansion headers is connected to two diodes and a resistor that provide protection from high and low voltages. The figure shows the protection circuitry for only four of the pins on each header, but this circuitry is included for all 72 data pins. Table 4.7 gives the pin assignments.

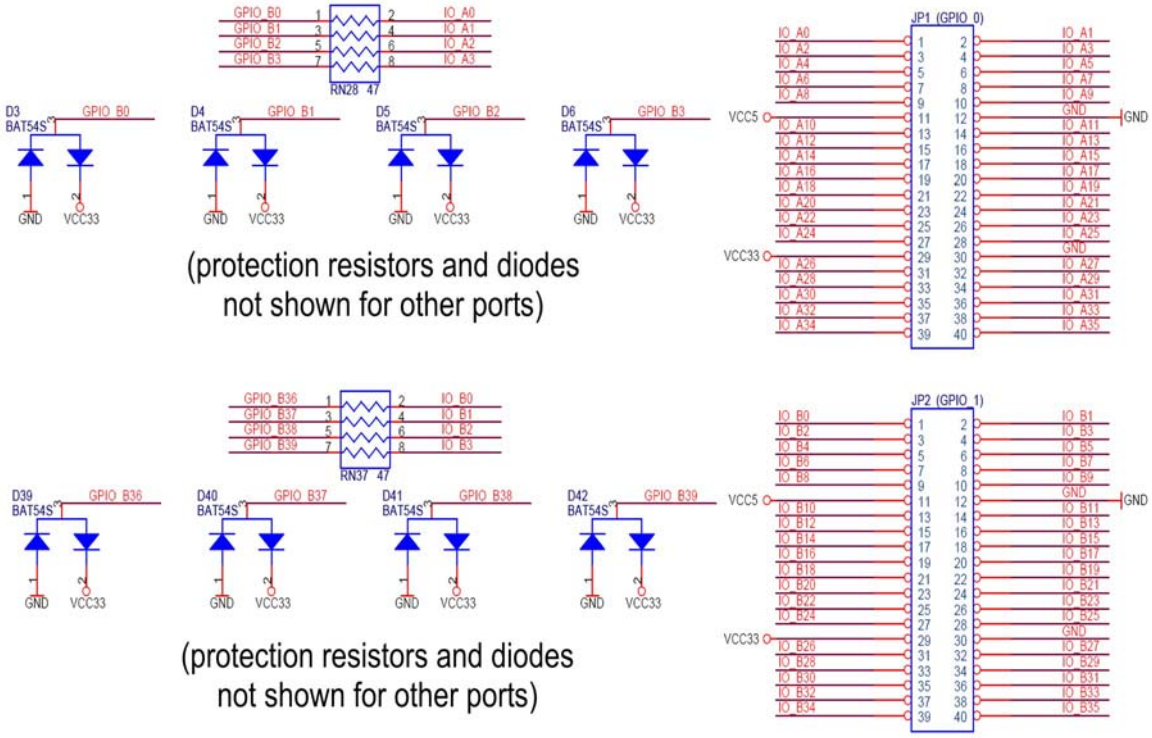

Figure 4.10. Schematic diagram of the expansion headers.

Signal Name	FPGA Pin No.	Description
GPIO_0[0]	PIN_D25	GPIO Connection 0[0]
GPIO_0[1]	PIN_J22	GPIO Connection 0[1]
GPIO_0[2]	PIN_E26	GPIO Connection 0[2]
GPIO_0[3]	PIN_E25	GPIO Connection 0[3]
GPIO_0[4]	PIN_F24	GPIO Connection 0[4]
GPIO_0[5]	PIN_F23	GPIO Connection 0[5]
GPIO_0[6]	PIN_J21	GPIO Connection 0[6]
GPIO_0[7]	PIN_J20	GPIO Connection 0[7]
GPIO_0[8]	PIN_F25	GPIO Connection 0[8]
GPIO_0[9]	PIN_F26	GPIO Connection 0[9]

GPIO_0[10]	PIN_N18	GPIO Connection 0[10]
GPIO_0[11]	PIN_P18	GPIO Connection 0[11]
GPIO_0[12]	PIN_G23	GPIO Connection 0[12]
GPIO_0[13]	PIN_G24	GPIO Connection 0[13]
GPIO_0[14]	PIN_K22	GPIO Connection 0[14]
GPIO_0[15]	PIN_G25	GPIO Connection 0[15]
GPIO_0[16]	PIN_H23	GPIO Connection 0[16]
GPIO_0[17]	PIN_H24	GPIO Connection 0[17]
GPIO_0[18]	PIN_J23	GPIO Connection 0[18]
GPIO_0[19]	PIN_J24	GPIO Connection 0[19]
GPIO_0[20]	PIN_H25	GPIO Connection 0[20]
GPIO_0[21]	PIN_H26	GPIO Connection 0[21]
GPIO_0[22]	PIN_H19	GPIO Connection 0[22]
GPIO_0[23]	PIN_K18	GPIO Connection 0[23]
GPIO_0[24]	PIN_K19	GPIO Connection 0[24]
GPIO_0[25]	PIN_K21	GPIO Connection 0[25]
GPIO_0[26]	PIN_K23	GPIO Connection 0[26]
GPIO_0[27]	PIN_K24	GPIO Connection 0[27]
GPIO_0[28]	PIN_L21	GPIO Connection 0[28]
GPIO_0[29]	PIN_L20	GPIO Connection 0[29]
GPIO_0[30]	PIN_J25	GPIO Connection 0[30]
GPIO_0[31]	PIN_J26	GPIO Connection 0[31]
GPIO_0[32]	PIN_L23	GPIO Connection 0[32]
GPIO_0[33]	PIN_L24	GPIO Connection 0[33]
GPIO_0[34]	PIN_L25	GPIO Connection 0[34]
GPIO_0[35]	PIN_L19	GPIO Connection 0[35]
GPIO_1[0]	PIN_K25	GPIO Connection 1[0]
GPIO_1[1]	PIN_K26	GPIO Connection 1[1]
GPIO_1[2]	PIN_M22	GPIO Connection 1[2]
GPIO_1[3]	PIN_M23	GPIO Connection 1[3]
GPIO_1[4]	PIN_M19	GPIO Connection 1[4]
GPIO_1[5]	PIN_M20	GPIO Connection 1[5]
GPIO_1[6]	PIN_N20	GPIO Connection 1[6]
GPIO_1[7]	PIN_M21	GPIO Connection 1[7]
GPIO_1[8]	PIN_M24	GPIO Connection 1[8]
GPIO_1[9]	PIN_M25	GPIO Connection 1[9]
GPIO_1[10]	PIN_N24	GPIO Connection 1[10]

GPIO_1[11]	PIN_P24	GPIO Connection 1[11]
GPIO_1[12]	PIN_R25	GPIO Connection 1[12]
GPIO_1[13]	PIN_R24	GPIO Connection 1[13]
GPIO_1[14]	PIN_R20	GPIO Connection 1[14]
GPIO_1[15]	PIN_T22	GPIO Connection 1[15]
GPIO_1[16]	PIN_T23	GPIO Connection 1[16]
GPIO_1[17]	PIN_T24	GPIO Connection 1[17]
GPIO_1[18]	PIN_T25	GPIO Connection 1[18]
GPIO_1[19]	PIN_T18	GPIO Connection 1[19]
GPIO_1[20]	PIN_T21	GPIO Connection 1[20]
GPIO_1[21]	PIN_T20	GPIO Connection 1[21]
GPIO_1[22]	PIN_U26	GPIO Connection 1[22]
GPIO_1[23]	PIN_U25	GPIO Connection 1[23]
GPIO_1[24]	PIN_U23	GPIO Connection 1[24]
GPIO_1[25]	PIN_U24	GPIO Connection 1[25]
GPIO_1[26]	PIN_R19	GPIO Connection 1[26]
GPIO_1[27]	PIN_T19	GPIO Connection 1[27]
GPIO_1[28]	PIN_U20	GPIO Connection 1[28]
GPIO_1[29]	PIN_U21	GPIO Connection 1[29]
GPIO_1[30]	PIN_V26	GPIO Connection 1[30]
GPIO_1[31]	PIN_V25	GPIO Connection 1[31]
GPIO_1[32]	PIN_V24	GPIO Connection 1[32]
GPIO_1[33]	PIN_V23	GPIO Connection 1[33]
GPIO_1[34]	PIN_W25	GPIO Connection 1[34]
GPIO_1[35]	PIN_W23	GPIO Connection 1[35]

Table 4.7. Pin assignments for the expansion headers.

4.7 Using VGA

The DE2 board includes a 16-pin D-SUB connector for VGA output. The VGA synchronization signals are provided directly from the Cyclone II FPGA, and the Analog Devices ADV7123 triple 10-bit high-speed video DAC is used to produce the analog data signals (red, green, and blue). The associated schematic is given in Figure 4.11 and can support resolutions of up to 1600 x 1200 pixels, at 100 MHz.

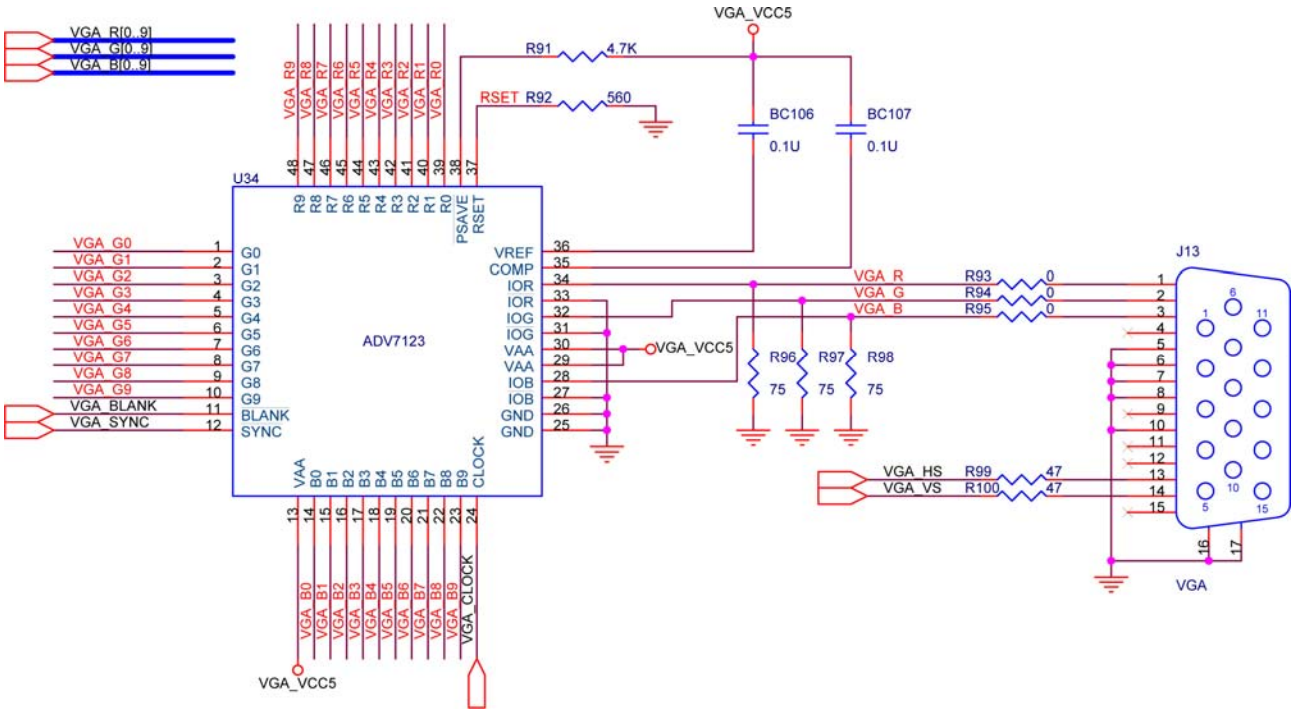

Figure 4.11. VGA circuit schematic.

The timing specification for VGA synchronization and RGB (red, green, blue) data can be found on various educational web sites (for example, search for “VGA signal timing”). Figure 4.12 illustrates the basic timing requirements for each row (horizontal) that is displayed on a VGA monitor. An active-low pulse of specific duration (time *a* in the figure) is applied to the horizontal synchronization (*hsync*) input of the monitor, which signifies the end of one row of data and the start of the next. The data (RGB) inputs on the monitor must be off (driven to 0 V) for a time period called the *back porch* (*b*) after the *hsync* pulse occurs, which is followed by the display interval (*c*). During the data display interval the RGB data drives each pixel in turn across the row being displayed. Finally, there is a time period called the *front porch* (*d*) where the RGB signals must again be off before the next *hsync* pulse can occur. The timing of the vertical synchronization (*vsync*) is the same as shown in Figure 4.12, except that a *vsync* pulse signifies the end of one frame and the start of the next, and the data refers to the set of rows in the frame (horizontal timing). Figures 4.13 and 4.14 show, for different resolutions, the durations of time periods *a*, *b*, *c*, and *d* for both horizontal and vertical timing.

Detailed information for using the ADV7123 video DAC is available in its datasheet, which can be found on the manufacturer's web site, and from the *Datasheet* folder on the **DE2 System CD-ROM**. The pin assignments between the Cyclone II FPGA and the ADV7123 are listed in Table 4.8. An example of code that drives a VGA display is described in Sections 5.2 and 5.3.

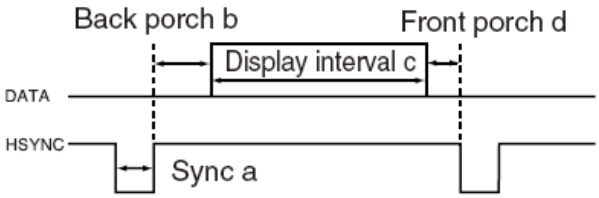

Figure 4.12. VGA horizontal timing specification.

VGA mode		Horizontal Timing Spec				
Configuration	Resolution(HxV)	a(us)	b(us)	c(us)	d(us)	Pixel clock(Mhz)
VGA(60Hz)	640x480	3.8	1.9	25.4	0.6	25 (640/c)
VGA(85Hz)	640x480	1.6	2.2	17.8	1.6	36 (640/c)
SVGA(60Hz)	800x600	3.2	2.2	20	1	40 (800/c)
SVGA(75Hz)	800x600	1.6	3.2	16.2	0.3	49 (800/c)
SVGA(85Hz)	800x600	1.1	2.7	14.2	0.6	56 (800/c)
XGA(60Hz)	1024x768	2.1	2.5	15.8	0.4	65 (1024/c)
XGA(70Hz)	1024x768	1.8	1.9	13.7	0.3	75 (1024/c)
XGA(85Hz)	1024x768	1.0	2.2	10.8	0.5	95 (1024/c)
1280x1024(60Hz)	1280x1024	1.0	2.3	11.9	0.4	108 (1280/c)

Figure 4.13. VGA horizontal timing specification.

VGA mode		Vertical Timing Spec			
Configuration	Resolution (HxV)	a(lines)	b(lines)	c(lines)	d(lines)
VGA(60Hz)	640x480	2	33	480	10
VGA(85Hz)	640x480	3	25	480	1
SVGA(60Hz)	800x600	4	23	600	1
SVGA(75Hz)	800x600	3	21	600	1
SVGA(85Hz)	800x600	3	27	600	1
XGA(60Hz)	1024x768	6	29	768	3
XGA(70Hz)	1024x768	6	29	768	3
XGA(85Hz)	1024x768	3	36	768	1
1280x1024(60Hz)	1280x1024	3	38	1024	1

Figure 4.14. VGA vertical timing specification.

Signal Name	FPGA Pin No.	Description
VGA_R[0]	PIN_C8	VGA Red[0]
VGA_R[1]	PIN_F10	VGA Red[1]
VGA_R[2]	PIN_G10	VGA Red[2]
VGA_R[3]	PIN_D9	VGA Red[3]
VGA_R[4]	PIN_C9	VGA Red[4]
VGA_R[5]	PIN_A8	VGA Red[5]
VGA_R[6]	PIN_H11	VGA Red[6]
VGA_R[7]	PIN_H12	VGA Red[7]
VGA_R[8]	PIN_F11	VGA Red[8]
VGA_R[9]	PIN_E10	VGA Red[9]
VGA_G[0]	PIN_B9	VGA Green[0]
VGA_G[1]	PIN_A9	VGA Green[1]
VGA_G[2]	PIN_C10	VGA Green[2]
VGA_G[3]	PIN_D10	VGA Green[3]
VGA_G[4]	PIN_B10	VGA Green[4]
VGA_G[5]	PIN_A10	VGA Green[5]
VGA_G[6]	PIN_G11	VGA Green[6]
VGA_G[7]	PIN_D11	VGA Green[7]
VGA_G[8]	PIN_E12	VGA Green[8]
VGA_G[9]	PIN_D12	VGA Green[9]
VGA_B[0]	PIN_J13	VGA Blue[0]
VGA_B[1]	PIN_J14	VGA Blue[1]
VGA_B[2]	PIN_F12	VGA Blue[2]
VGA_B[3]	PIN_G12	VGA Blue[3]
VGA_B[4]	PIN_J10	VGA Blue[4]
VGA_B[5]	PIN_J11	VGA Blue[5]
VGA_B[6]	PIN_C11	VGA Blue[6]
VGA_B[7]	PIN_B11	VGA Blue[7]
VGA_B[8]	PIN_C12	VGA Blue[8]
VGA_B[9]	PIN_B12	VGA Blue[9]
VGA_CLK	PIN_B8	VGA Clock
VGA_BLANK	PIN_D6	VGA BLANK
VGA_HS	PIN_A7	VGA H_SYNC
VGA_VS	PIN_D8	VGA V_SYNC
VGA_SYNC	PIN_B7	VGA SYNC

Table 4.8. ADV7123 pin assignments.

4.8 Using the 24-bit Audio CODEC

The DE2 board provides high-quality 24-bit audio via the Wolfson WM8731 audio CODEC (enCOder/DECoder). This chip supports microphone-in, line-in, and line-out ports, with a sample rate adjustable from 8 kHz to 96 kHz. The WM8731 is controlled by a serial I2C bus interface, which is connected to pins on the Cyclone II FPGA. A schematic diagram of the audio circuitry is shown in Figure 4.15, and the FPGA pin assignments are listed in Table 4.9. Detailed information for using the WM8731 codec is available in its datasheet, which can be found on the manufacturer's web site, and from the *Datasheet* folder on the **DE2 System CD-ROM**.

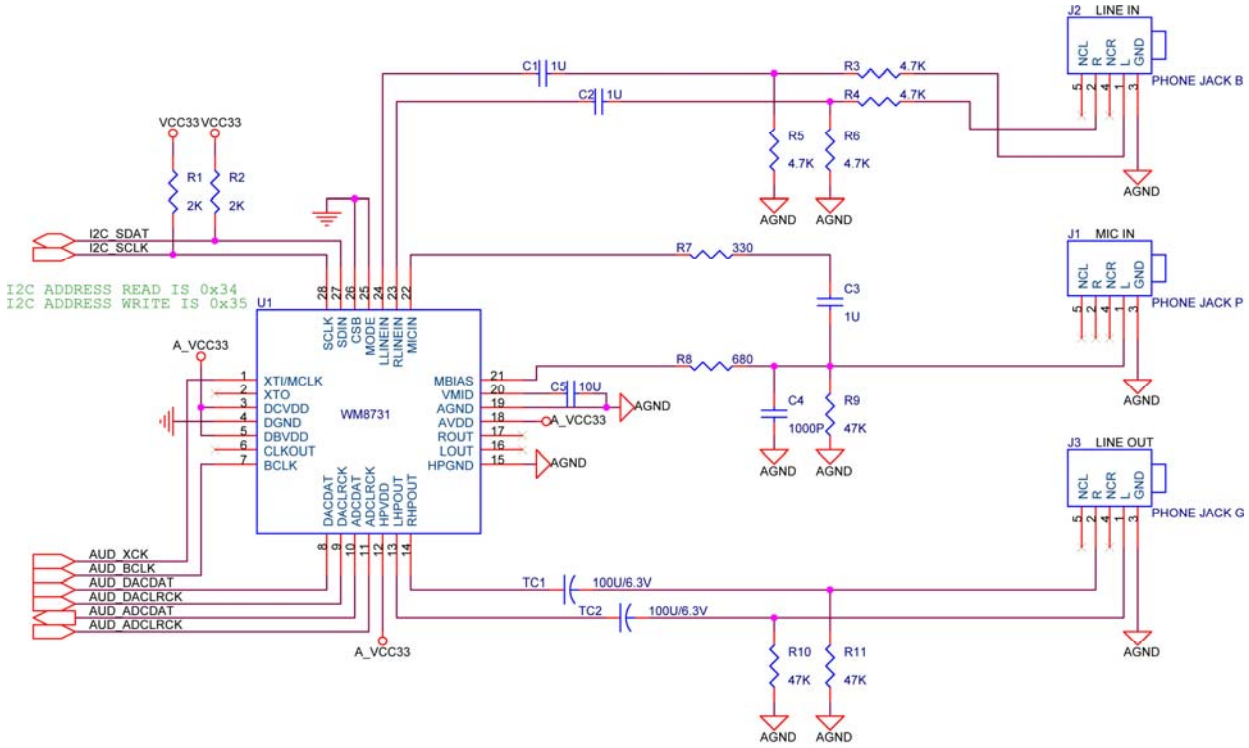

Figure 4.15. Audio CODEC schematic.

Signal Name	FPGA Pin No.	Description
AUD_ADCLRCK	PIN_C5	Audio CODEC ADC LR Clock
AUD_ADCDAT	PIN_B5	Audio CODEC ADC Data
AUD_DACLRCK	PIN_C6	Audio CODEC DAC LR Clock
AUD_DACDAT	PIN_A4	Audio CODEC DAC Data
AUD_XCK	PIN_A5	Audio CODEC Chip Clock
AUD_BCLK	PIN_B4	Audio CODEC Bit-Stream Clock
I2C_SCLK	PIN_A6	I2C Data
I2C_SDAT	PIN_B6	I2C Clock

Table 4.9. Audio CODEC pin assignments.

4.9 RS-232 Serial Port

The DE2 board uses the MAX232 transceiver chip and a 9-pin D-SUB connector for RS-232 communications. For detailed information on how to use the transceiver refer to the datasheet, which is available on the manufacturer's web site, and from the *Datasheet* folder on the **DE2 System CD-ROM**. Figure 4.16 shows the related schematics, and Table 4.10 lists the Cyclone II FPGA pin assignments.

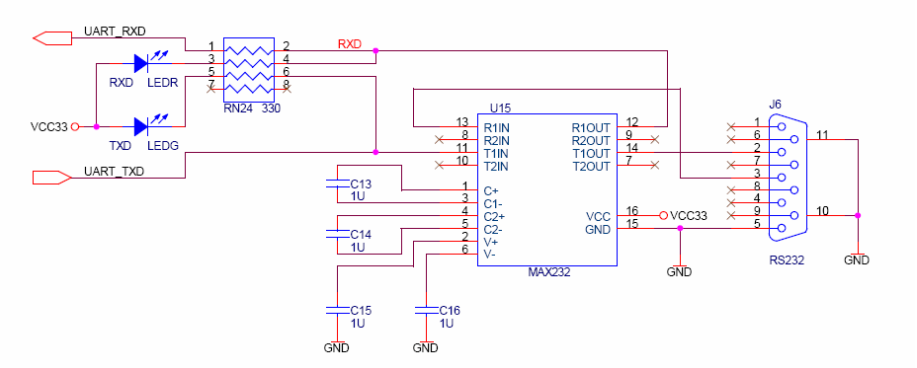

Figure 4.16. MAX232 (RS-232) chip schematic.

Signal Name	FPGA Pin No.	Description
UART_RXD	PIN_C25	UART Receiver
UART_TXD	PIN_B25	UART Transmitter

Table 4.10. RS-232 pin assignments.

4.10 PS/2 Serial Port

The DE2 board includes a standard PS/2 interface and a connector for a PS/2 keyboard or mouse. Figure 4.17 shows the schematic of the PS/2 circuit. Instructions for using a PS/2 mouse or keyboard can be found by performing an appropriate search on various educational web sites. The pin assignments for the associated interface are shown in Table 4.11.

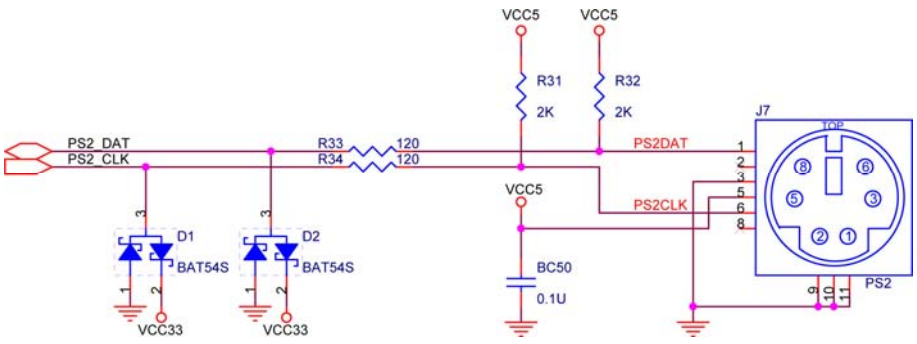

Figure 4.17. PS/2 schematic.

Signal Name	FPGA Pin No.	Description
PS2_CLK	PIN_D26	PS/2 Clock
PS2_DAT	PIN_C24	PS/2 Data

Table 4.11. PS/2 pin assignments.

4.11 Fast Ethernet Network Controller

The DE2 board provides Ethernet support via the Davicom DM9000A Fast Ethernet controller chip. The DM9000A includes a general processor interface, 16 Kbytes SRAM, a media access control (MAC) unit, and a 10/100M PHY transceiver. Figure 4.18 shows the schematic for the Fast Ethernet interface, and the associated pin assignments are listed in Table 4.12. For detailed information on how to use the DM9000A refer to its datasheet and application note, which are available on the manufacturer's web site, and from the *Datasheet* folder on the **DE2 System CD-ROM**.

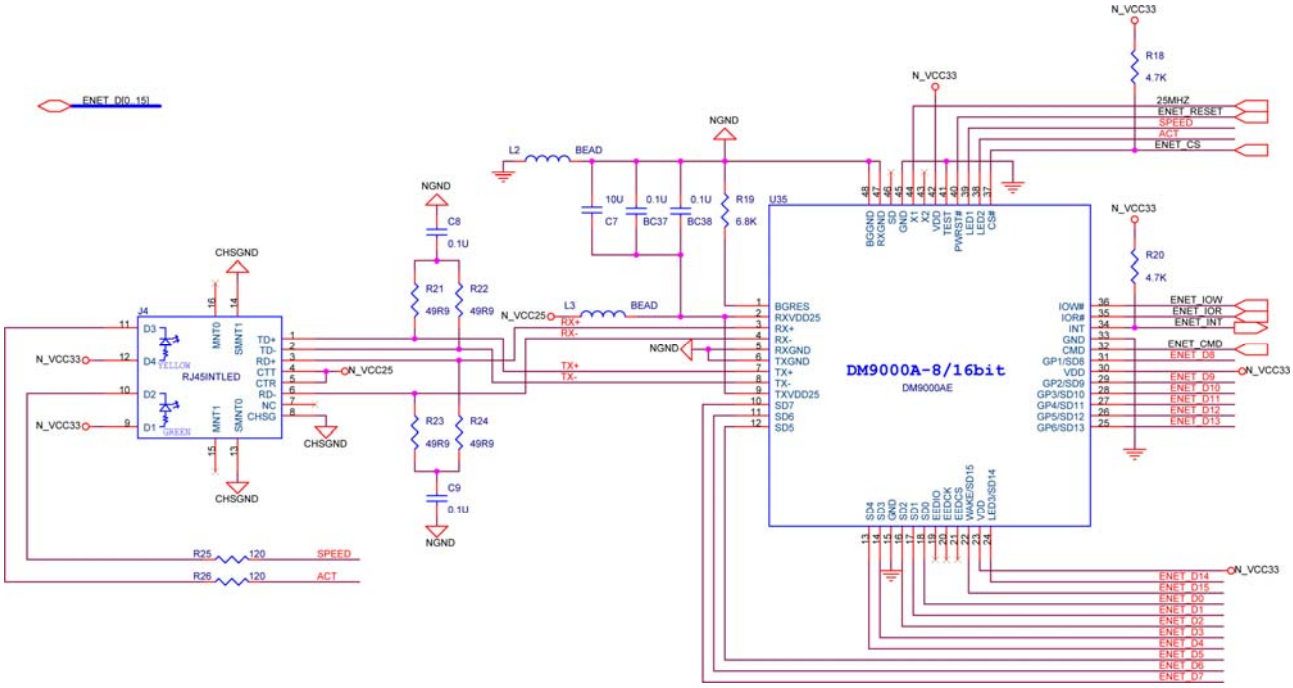

Figure 4.18. Fast Ethernet schematic.

Signal Name	FPGA Pin No.	Description
ENET_DATA[0]	PIN_D17	DM9000A DATA[0]
ENET_DATA[1]	PIN_C17	DM9000A DATA[1]
ENET_DATA[2]	PIN_B18	DM9000A DATA[2]
ENET_DATA[3]	PIN_A18	DM9000A DATA[3]
ENET_DATA[4]	PIN_B17	DM9000A DATA[4]

ENET_DATA[5]	PIN_A17	DM9000A DATA[5]
ENET_DATA[6]	PIN_B16	DM9000A DATA[6]
ENET_DATA[7]	PIN_B15	DM9000A DATA[7]
ENET_DATA[8]	PIN_B20	DM9000A DATA[8]
ENET_DATA[9]	PIN_A20	DM9000A DATA[9]
ENET_DATA[10]	PIN_C19	DM9000A DATA[10]
ENET_DATA[11]	PIN_D19	DM9000A DATA[11]
ENET_DATA[12]	PIN_B19	DM9000A DATA[12]
ENET_DATA[13]	PIN_A19	DM9000A DATA[13]
ENET_DATA[14]	PIN_E18	DM9000A DATA[14]
ENET_DATA[15]	PIN_D18	DM9000A DATA[15]
ENET_CLK	PIN_B24	DM9000A Clock 25 MHz
ENET_CMD	PIN_A21	DM9000A Command/Data Select, 0 = Command, 1 = Data
ENET_CS_N	PIN_A23	DM9000A Chip Select
ENET_INT	PIN_B21	DM9000A Interrupt
ENET_RD_N	PIN_A22	DM9000A Read
ENET_WR_N	PIN_B22	DM9000A Write
ENET_RST_N	PIN_B23	DM9000A Reset

Table 4.12. Fast Ethernet pin assignments.

4.12 TV Decoder

The DE2 board is equipped with an Analog Devices ADV7181 TV decoder chip. The ADV7181 is an integrated video decoder that automatically detects and converts a standard analog baseband television signal (NTSC, PAL, and SECAM) into 4:2:2 component video data compatible with 16-bit/8-bit CCIR601/CCIR656. The ADV7181 is compatible with a broad range of video devices, including DVD players, tape-based sources, broadcast sources, and security/surveillance cameras.

The registers in the TV decoder can be programmed by a serial I2C bus, which is connected to the Cyclone II FPGA as indicated in Figure 4.19. The pin assignments are listed in Table 4.13. Detailed information on the ADV7181 is available on the manufacturer's web site, and from the *Datasheet* folder on the **DE2 System CD-ROM**.

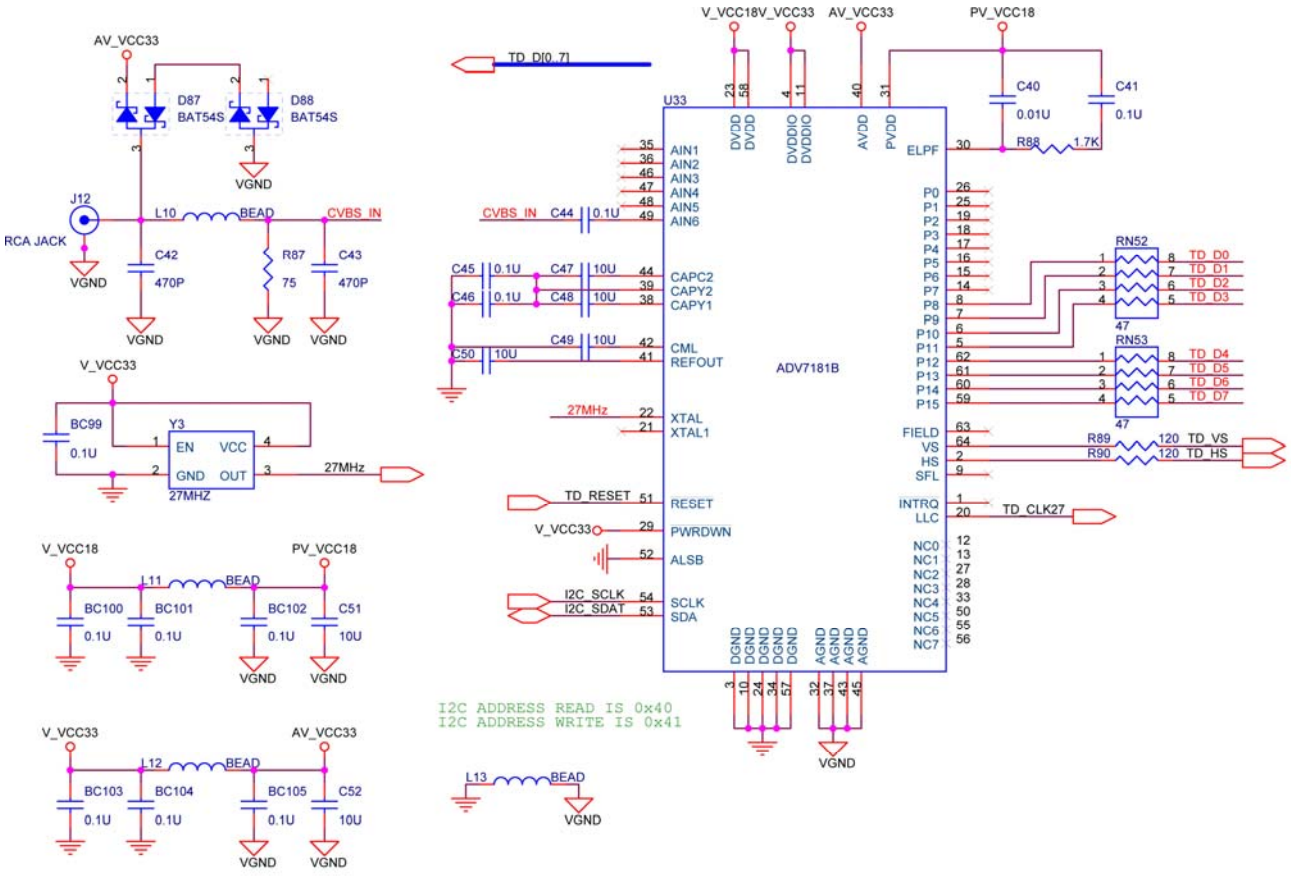

Figure 4.19. TV Decoder schematic.

Signal Name	FPGA Pin No.	Description
TD_DATA[0]	PIN_J9	TV Decoder Data[0]
TD_DATA[1]	PIN_E8	TV Decoder Data[1]
TD_DATA[2]	PIN_H8	TV Decoder Data[2]
TD_DATA[3]	PIN_H10	TV Decoder Data[3]
TD_DATA[4]	PIN_G9	TV Decoder Data[4]
TD_DATA[5]	PIN_F9	TV Decoder Data[5]
TD_DATA[6]	PIN_D7	TV Decoder Data[6]
TD_DATA[7]	PIN_C7	TV Decoder Data[7]
TD_HS	PIN_D5	TV Decoder H_SYNC
TD_VS	PIN_K9	TV Decoder V_SYNC
TD_CLK27	PIN_C16	TV Decoder Clock Input.
TD_RESET	PIN_C4	TV Decoder Reset
I2C_SCLK	PIN_A6	I2C Data
I2C_SDAT	PIN_B6	I2C Clock

Table 4.13. TV Decoder pin assignments.

4.13 Implementing a TV Encoder

Although the DE2 board does not include a TV encoder chip, the ADV7123 (10-bit high-speed triple ADCs) can be used to implement a professional-quality TV encoder with the digital processing part implemented in the Cyclone II FPGA. Figure 4.20 shows a block diagram of a TV encoder implemented in this manner.

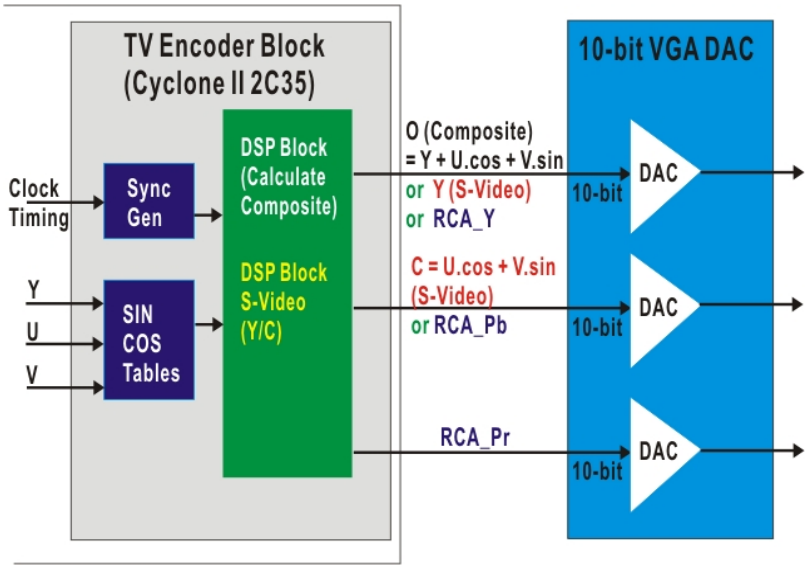

Figure 4.20. A TV Encoder that uses the Cyclone II FPGA and the ADV7123.

4.14 Using USB Host and Device

The DE2 board provides both USB host and device interfaces using the Philips ISP1362 single-chip USB controller. The host and device controllers are compliant with the Universal Serial Bus Specification Rev. 2.0, supporting data transfer at full-speed (12 Mbit/s) and low-speed (1.5 Mbit/s). Figure 4.21 shows the schematic diagram of the USB circuitry; the pin assignments for the associated interface are listed in Table 4.14.

Detailed information for using the ISP1362 device is available in its datasheet and programming guide; both documents can be found on the manufacturer's web site, and from the *Datasheet* folder on the **DE2 System CD-ROM**. The most challenging part of a USB application is in the design of the software driver needed. Two complete examples of USB drivers, for both host and device applications, can be found in Sections 5.3 and 5.4. These demonstrations provide examples of software drivers for the Nios II processor.

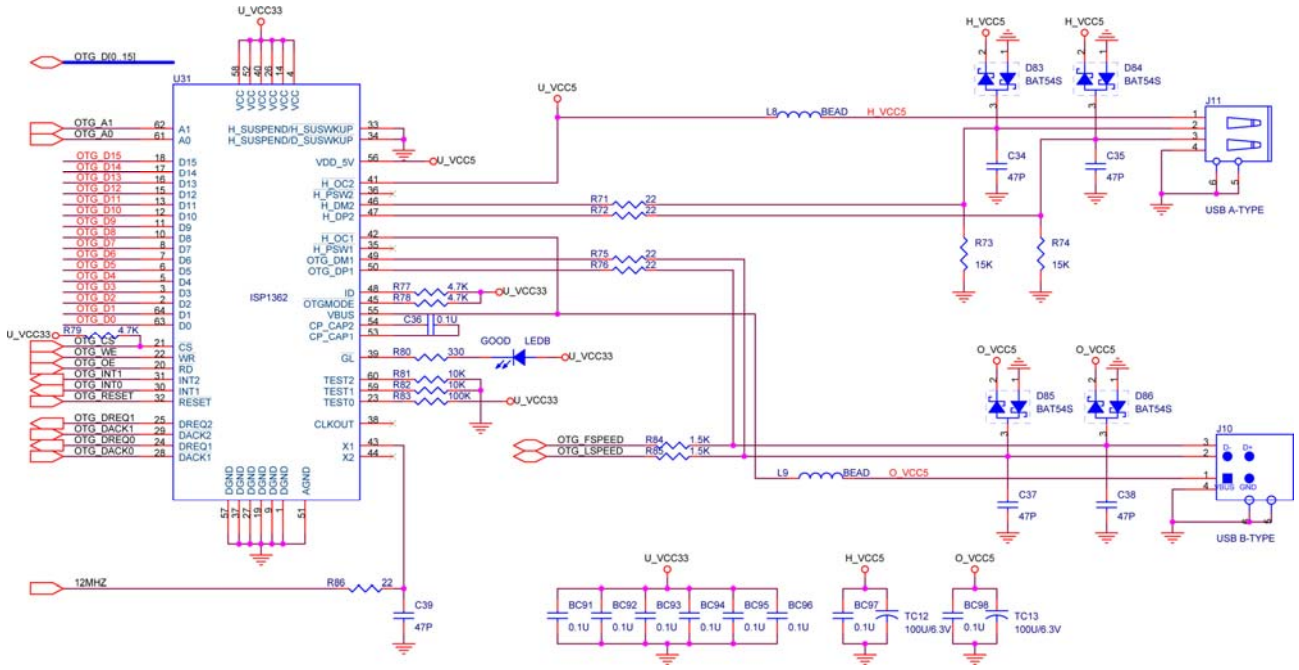

Figure 4.21. USB (ISP1362) host and device schematic.

Signal Name	FPGA Pin No.	Description
OTG_ADDR[0]	PIN_K7	ISP1362 Address[0]
OTG_ADDR[1]	PIN_F2	ISP1362 Address[1]
OTG_DATA[0]	PIN_F4	ISP1362 Data[0]
OTG_DATA[1]	PIN_D2	ISP1362 Data[1]
OTG_DATA[2]	PIN_D1	ISP1362 Data[2]
OTG_DATA[3]	PIN_F7	ISP1362 Data[3]
OTG_DATA[4]	PIN_J5	ISP1362 Data[4]
OTG_DATA[5]	PIN_J8	ISP1362 Data[5]
OTG_DATA[6]	PIN_J7	ISP1362 Data[6]
OTG_DATA[7]	PIN_H6	ISP1362 Data[7]
OTG_DATA[8]	PIN_E2	ISP1362 Data[8]
OTG_DATA[9]	PIN_E1	ISP1362 Data[9]
OTG_DATA[10]	PIN_K6	ISP1362 Data[10]
OTG_DATA[11]	PIN_K5	ISP1362 Data[11]
OTG_DATA[12]	PIN_G4	ISP1362 Data[12]
OTG_DATA[13]	PIN_G3	ISP1362 Data[13]
OTG_DATA[14]	PIN_J6	ISP1362 Data[14]
OTG_DATA[15]	PIN_K8	ISP1362 Data[15]
OTG_CS_N	PIN_F1	ISP1362 Chip Select
OTG_RD_N	PIN_G2	ISP1362 Read

OTG_WR_N	PIN_G1	ISP1362 Write
OTG_RST_N	PIN_G5	ISP1362 Reset
OTG_INT0	PIN_B3	ISP1362 Interrupt 0
OTG_INT1	PIN_C3	ISP1362 Interrupt 1
OTG_DACK0_N	PIN_C2	ISP1362 DMA Acknowledge 0
OTG_DACK1_N	PIN_B2	ISP1362 DMA Acknowledge 1
OTG_DREQ0	PIN_F6	ISP1362 DMA Request 0
OTG_DREQ1	PIN_E5	ISP1362 DMA Request 1
OTG_FSPEED	PIN_F3	USB Full Speed, 0 = Enable, Z = Disable
OTG_LSPEED	PIN_G6	USB Low Speed, 0 = Enable, Z = Disable

Table 4.14. USB (ISP1362) pin assignments.

4.15 Using IrDA

The DE2 board provides a simple wireless communication media using the Agilent HSDL-3201 low power infrared transceiver. The datasheet for this device is provided in the *Datasheet\IrDA* folder on the **DE2 System CD-ROM**. Note that the highest transmission rate supported is 115.2 Kbit/s and both the TX and RX sides have to use the same transmission rate. Figure 4.22 shows the schematic of the IrDA communication link. Please refer to the following website for detailed information on how to send and receive data using the IrDA link: http://techtrain.microchip.com/webseminars/documents/IrDA_BW.pdf.
The pin assignment of the associated interface are listed in Table 4.15.

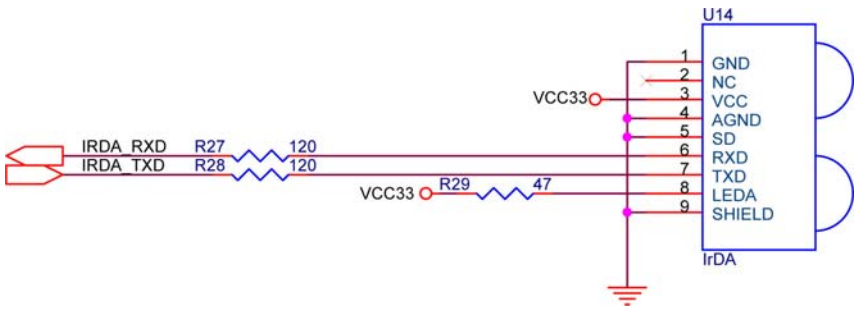

Figure 4.22. IrDA schematic.

Signal Name	FPGA Pin No.	Description
IRDA_TXD	PIN_AE24	IRDA Transmitter
IRDA_RXD	PIN_AE25	IRDA Receiver

Table 4.15. IrDA pin assignments.

4.16 Using SDRAM/SRAM/Flash

The DE2 board provides an 8-Mbyte SDRAM, 512-Kbyte SRAM, and 4-Mbyte (1-Mbyte on some boards) Flash memory. Figures 4.23, 4.24, and 4.25 show the schematics of the memory chips. The pin assignments for each device are listed in Tables 4.16, 4.17, and 4.18. The datasheets for the memory chips are provided in the *Datasheet* folder on the **DE2 System CD-ROM**.

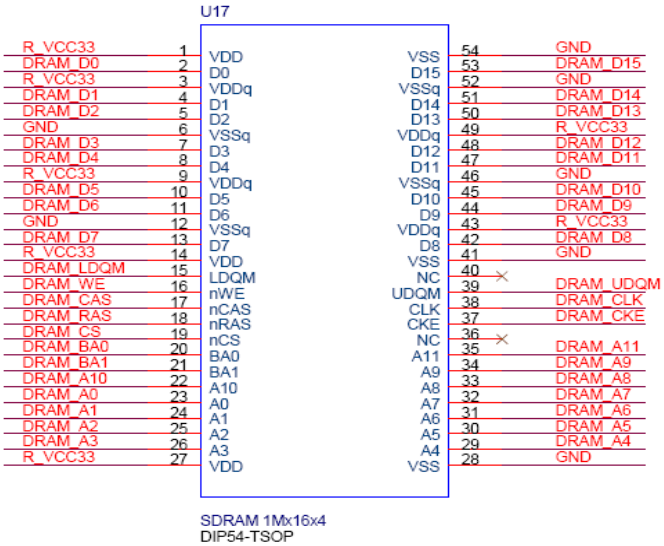

Figure 4.23. SDRAM schematic.

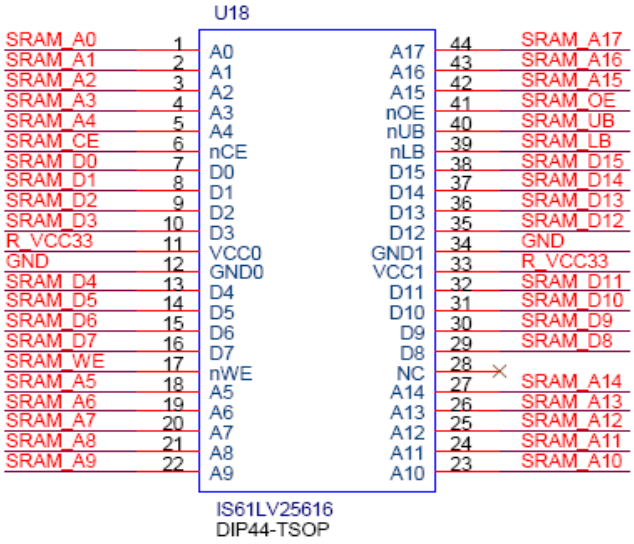

Figure 4.24. SRAM schematic.

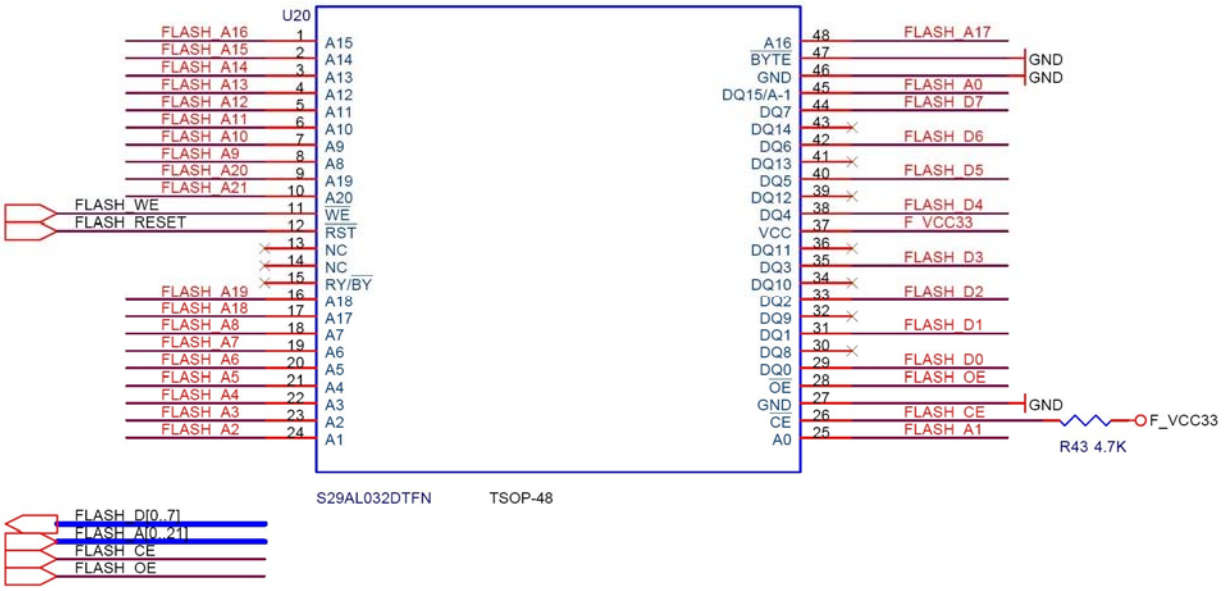

Figure 4.25. Flash schematic.

Signal Name	FPGA Pin No.	Description
DRAM_ADDR[0]	PIN_T6	SDRAM Address[0]
DRAM_ADDR[1]	PIN_V4	SDRAM Address[1]
DRAM_ADDR[2]	PIN_V3	SDRAM Address[2]
DRAM_ADDR[3]	PIN_W2	SDRAM Address[3]
DRAM_ADDR[4]	PIN_W1	SDRAM Address[4]
DRAM_ADDR[5]	PIN_U6	SDRAM Address[5]
DRAM_ADDR[6]	PIN_U7	SDRAM Address[6]
DRAM_ADDR[7]	PIN_U5	SDRAM Address[7]
DRAM_ADDR[8]	PIN_W4	SDRAM Address[8]
DRAM_ADDR[9]	PIN_W3	SDRAM Address[9]
DRAM_ADDR[10]	PIN_Y1	SDRAM Address[10]
DRAM_ADDR[11]	PIN_V5	SDRAM Address[11]
DRAM_DQ[0]	PIN_V6	SDRAM Data[0]
DRAM_DQ[1]	PIN_AA2	SDRAM Data[1]
DRAM_DQ[2]	PIN_AA1	SDRAM Data[2]
DRAM_DQ[3]	PIN_Y3	SDRAM Data[3]
DRAM_DQ[4]	PIN_Y4	SDRAM Data[4]
DRAM_DQ[5]	PIN_R8	SDRAM Data[5]
DRAM_DQ[6]	PIN_T8	SDRAM Data[6]
DRAM_DQ[7]	PIN_V7	SDRAM Data[7]
DRAM_DQ[8]	PIN_W6	SDRAM Data[8]

DRAM_DQ[9]	PIN_AB2	SDRAM Data[9]
DRAM_DQ[10]	PIN_AB1	SDRAM Data[10]
DRAM_DQ[11]	PIN_AA4	SDRAM Data[11]
DRAM_DQ[12]	PIN_AA3	SDRAM Data[12]
DRAM_DQ[13]	PIN_AC2	SDRAM Data[13]
DRAM_DQ[14]	PIN_AC1	SDRAM Data[14]
DRAM_DQ[15]	PIN_AA5	SDRAM Data[15]
DRAM_BA_0	PIN_AE2	SDRAM Bank Address[0]
DRAM_BA_1	PIN_AE3	SDRAM Bank Address[1]
DRAM_LDQM	PIN_AD2	SDRAM Low-byte Data Mask
DRAM_UDQM	PIN_Y5	SDRAM High-byte Data Mask
DRAM_RAS_N	PIN_AB4	SDRAM Row Address Strobe
DRAM_CAS_N	PIN_AB3	SDRAM Column Address Strobe
DRAM_CKE	PIN_AA6	SDRAM Clock Enable
DRAM_CLK	PIN_AA7	SDRAM Clock
DRAM_WE_N	PIN_AD3	SDRAM Write Enable
DRAM_CS_N	PIN_AC3	SDRAM Chip Select

Table 4.16. SDRAM pin assignments.

Signal Name	FPGA Pin No.	Description
SRAM_ADDR[0]	PIN_AE4	SRAM Address[0]
SRAM_ADDR[1]	PIN_AF4	SRAM Address[1]
SRAM_ADDR[2]	PIN_AC5	SRAM Address[2]
SRAM_ADDR[3]	PIN_AC6	SRAM Address[3]
SRAM_ADDR[4]	PIN_AD4	SRAM Address[4]
SRAM_ADDR[5]	PIN_AD5	SRAM Address[5]
SRAM_ADDR[6]	PIN_AE5	SRAM Address[6]
SRAM_ADDR[7]	PIN_AF5	SRAM Address[7]
SRAM_ADDR[8]	PIN_AD6	SRAM Address[8]
SRAM_ADDR[9]	PIN_AD7	SRAM Address[9]
SRAM_ADDR[10]	PIN_V10	SRAM Address[10]
SRAM_ADDR[11]	PIN_V9	SRAM Address[11]
SRAM_ADDR[12]	PIN_AC7	SRAM Address[12]
SRAM_ADDR[13]	PIN_W8	SRAM Address[13]
SRAM_ADDR[14]	PIN_W10	SRAM Address[14]
SRAM_ADDR[15]	PIN_Y10	SRAM Address[15]

SRAM_ADDR[16]	PIN_AB8	SRAM Address[16]
SRAM_ADDR[17]	PIN_AC8	SRAM Address[17]
SRAM_DQ[0]	PIN_AD8	SRAM Data[0]
SRAM_DQ[1]	PIN_AE6	SRAM Data[1]
SRAM_DQ[2]	PIN_AF6	SRAM Data[2]
SRAM_DQ[3]	PIN_AA9	SRAM Data[3]
SRAM_DQ[4]	PIN_AA10	SRAM Data[4]
SRAM_DQ[5]	PIN_AB10	SRAM Data[5]
SRAM_DQ[6]	PIN_AA11	SRAM Data[6]
SRAM_DQ[7]	PIN_Y11	SRAM Data[7]
SRAM_DQ[8]	PIN_AE7	SRAM Data[8]
SRAM_DQ[9]	PIN_AF7	SRAM Data[9]
SRAM_DQ[10]	PIN_AE8	SRAM Data[10]
SRAM_DQ[11]	PIN_AF8	SRAM Data[11]
SRAM_DQ[12]	PIN_W11	SRAM Data[12]
SRAM_DQ[13]	PIN_W12	SRAM Data[13]
SRAM_DQ[14]	PIN_AC9	SRAM Data[14]
SRAM_DQ[15]	PIN_AC10	SRAM Data[15]
SRAM_WE_N	PIN_AE10	SRAM Write Enable
SRAM_OE_N	PIN_AD10	SRAM Output Enable
SRAM_UB_N	PIN_AF9	SRAM High-byte Data Mask
SRAM_LB_N	PIN_AE9	SRAM Low-byte Data Mask
SRAM_CE_N	PIN_AC11	SRAM Chip Enable

Table 4.17. SRAM pin assignments.

Signal Name	FPGA Pin No.	Description
FL_ADDR[0]	PIN_AC18	FLASH Address[0]
FL_ADDR[1]	PIN_AB18	FLASH Address[1]
FL_ADDR[2]	PIN_AE19	FLASH Address[2]
FL_ADDR[3]	PIN_AF19	FLASH Address[3]
FL_ADDR[4]	PIN_AE18	FLASH Address[4]
FL_ADDR[5]	PIN_AF18	FLASH Address[5]
FL_ADDR[6]	PIN_Y16	FLASH Address[6]
FL_ADDR[7]	PIN_AA16	FLASH Address[7]
FL_ADDR[8]	PIN_AD17	FLASH Address[8]
FL_ADDR[9]	PIN_AC17	FLASH Address[9]

FL_ADDR[10]	PIN_AE17	FLASH Address[10]
FL_ADDR[11]	PIN_AF17	FLASH Address[11]
FL_ADDR[12]	PIN_W16	FLASH Address[12]
FL_ADDR[13]	PIN_W15	FLASH Address[13]
FL_ADDR[14]	PIN_AC16	FLASH Address[14]
FL_ADDR[15]	PIN_AD16	FLASH Address[15]
FL_ADDR[16]	PIN_AE16	FLASH Address[16]
FL_ADDR[17]	PIN_AC15	FLASH Address[17]
FL_ADDR[18]	PIN_AB15	FLASH Address[18]
FL_ADDR[19]	PIN_AA15	FLASH Address[19]
FL_ADDR[20]	PIN_Y15	FLASH Address[20]
FL_ADDR[21]	PIN_Y14	FLASH Address[21]
FL_DQ[0]	PIN_AD19	FLASH Data[0]
FL_DQ[1]	PIN_AC19	FLASH Data[1]
FL_DQ[2]	PIN_AF20	FLASH Data[2]
FL_DQ[3]	PIN_AE20	FLASH Data[3]
FL_DQ[4]	PIN_AB20	FLASH Data[4]
FL_DQ[5]	PIN_AC20	FLASH Data[5]
FL_DQ[6]	PIN_AF21	FLASH Data[6]
FL_DQ[7]	PIN_AE21	FLASH Data[7]
FL_CE_N	PIN_V17	FLASH Chip Enable
FL_OE_N	PIN_W17	FLASH Output Enable
FL_RST_N	PIN_AA18	FLASH Reset
FL_WE_N	PIN_AA17	FLASH Write Enable

Table 4.18. Flash pin assignments.

Chapter 5
Examples of Advanced Demonstrations

This chapter provides a number of examples of advanced circuits implemented on the DE2 board. These circuits provide demonstrations of the major features on the board, such as its audio and video capabilities, and USB and Ethernet connectivity. For each demonstration the Cyclone II FPGA (or EPCS16 serial EEPROM) configuration file is provided, as well as the full source code in Verilog HDL code. All of the associated files can be found in the *DE2_demonstrations* folder from the **DE2 System CD-ROM**. For each of demonstrations described in the following sections, we give the name of the project directory for its files, which are subdirectories of the *DE2_demonstrations* folder.

Installing the Demonstrations

To install the demonstrations on your computer, perform the following

1. Copy the directory *DE2_demonstrations* into a local directory of your choice. It is important to ensure that the path to your local directory contains no spaces – otherwise, the Nios II software will not work.
2. In the directory *DE2_demonstrations*, go to the subdirectory *fixpaths*.
3. Run the *DE2_fixpaths.bat* batch file. In the dialog box that pops up, select the directory *DE2_demonstrations* in your local directory where you copied the files to. Click OK.
4. When *fixpaths* is finished, press any key to complete the process.

5.1 DE2 Factory Configuration

The DE2 board is shipped from the factory with a default configuration that demonstrates some of the basic features of the board. The setup required for this demonstration, and the locations of its files are shown below.

Demonstration Setup, File Locations, and Instructions

- Project directory: *DE2_Default*
- Bit stream used: *DE2_Default.sof* or *DE2_Default.pof*

- Power on the DE2 board, with the USB cable connected to the USB Blaster port. If necessary (that is, if the default factory configuration of the DE2 board is not currently stored in EPCS16 device), download the bit stream to the board by using either JTAG or AS programming
- You should now be able to observe that the 7-segment displays are displaying a sequence of characters, and the red and green LEDs are flashing. Also, **Welcome to the Altera DE2 Board** is shown on the LCD display
- Optionally connect a VGA display to the VGA D-SUB connector. When connected, the VGA display should show a pattern of colors.
- Optionally connect a powered speaker to the stereo audio-out jack
- Place toggle switch SW17 in the UP position to hear a 1 kHz humming sound from the audio-out port. Alternatively, if switch SW17 is DOWN, the microphone-in port can be connected to a microphone to hear voice sounds, or the line-in port can be used to play audio from an appropriate sound source.

The Verilog source code for this demonstration is provided in the *DE2_Default* folder, which also includes the necessary files for the corresponding Quartus II project. The top-level Verilog file, called *DE2_Default.v*, can be used as a template for other projects, because it defines ports that correspond to all of the user-accessible pins on the Cyclone II FPGA.

5.2 TV Box Demonstration

This demonstration plays video and audio input from a DVD player using the VGA output and audio CODEC on the DE2 board. Figure 5.1 shows the block diagram of the design. There are two major blocks in the circuit, called *I2C_AV_Config* and *TV_to_VGA*. The *TV_to_VGA* block consists of the *ITU-R 656 Decoder*, *SDRAM Frame Buffer*, *YUV422 to YUV444*, *YCrCb to RGB*, and *VGA Controller*. The figure also shows the TV Decoder (ADV7181) and the VGA DAC (ADV7123) chips used.

As soon as the bit stream is downloaded into the FPGA, the register values of the TV Decoder chip are used to configure the TV decoder via the *I2C_AV_Config* block, which uses the I2C protocol to communicate with the TV Decoder chip. Following the power-on sequence, the TV Decoder chip will be unstable for a time period; the *Lock Detector* is responsible for detecting this instability.

The *ITU-R 656 Decoder* block extracts *YCrCb 4:2:2 (YUV 4:2:2)* video signals from the *ITU-R 656* data stream sent from the TV Decoder. It also generates a data valid control signal indicating the valid period of data output. Because the video signal from the TV Decoder is interlaced, we need to perform de-interlacing on the data source. We used the *SDRAM Frame Buffer* and a *field selection multiplexer(*MUX*)* which is controled by the *VGA controller* to perform the de-interlacing operation.

Internally, the *VGA Controller* generates data request and odd/even selected signals to the *SDRAM Frame Buffer* and *filed selection multiplexer(*MUX*)*. The *YUV422 to YUV444* block converts the selected *YCrCb 4:2:2 (YUV 4:2:2)* video data to the *YCrCb 4:4:4 (YUV 4:4:4)* video data format.

Finally, the *YCrCb_to_RGB* block converts the *YCrCb* data into RGB output. The *VGA Controller* block generates standard VGA sync signals *VGA_HS* and *VGA_VS* to enable the display on a VGA monitor.

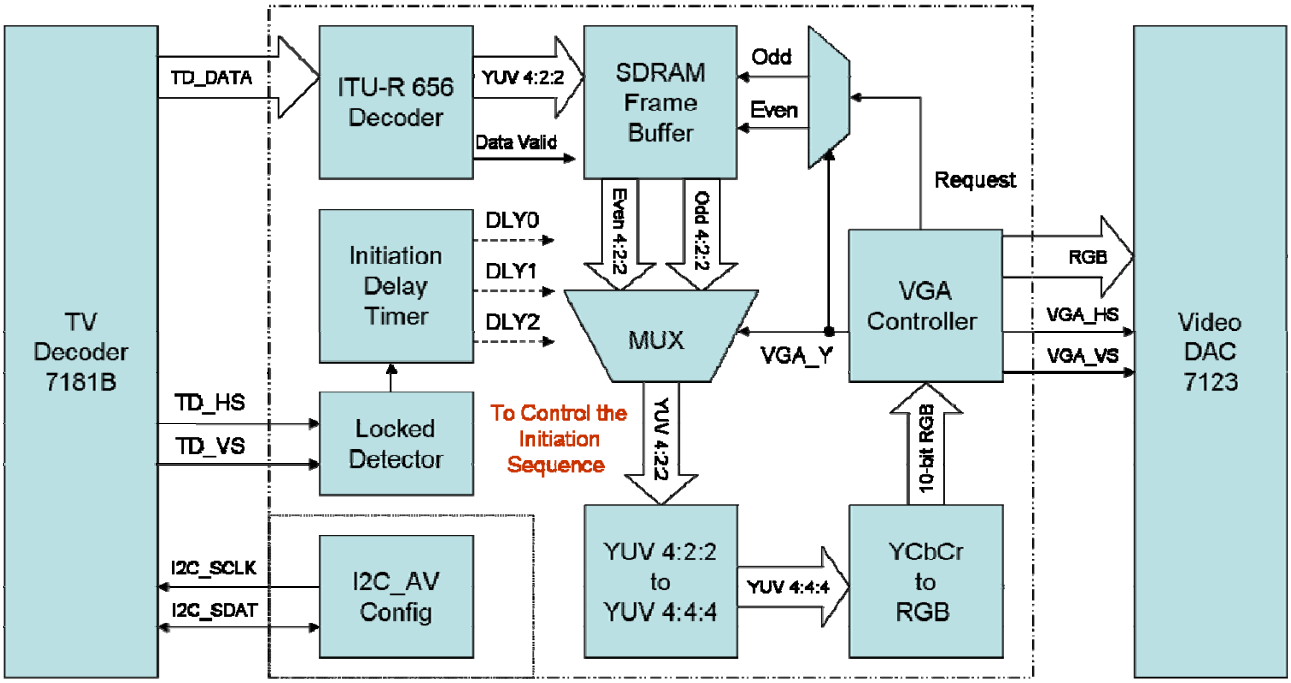

Figure 5.1. Block diagram of the TV box demonstration.

Demonstration Setup, File Locations, and Instructions

- Project directory: *DE2_TV*
- Bit stream used: *DE2_TV.sof* or *DE2_TV.pof*
- Connect a DVD player's composite video output (yellow plug) to the Video-in RCA jack of the DE2 board. The DVD player has to be configured to provide
  - NTSC output
  - 60 Hz refresh rate
  - 4:3 aspect ratio
- Non-progressive video
- Connect the VGA output of the DE2 board to a VGA monitor (both LCD and CRT type of monitors should work)

- Connect the audio output of the DVD player to the line-in port of the DE2 board and connect a speaker to the line-out port. If the audio output jacks from the DVD player are of RCA type, then an adaptor will be needed to convert to the mini-stereo plug supported on the DE2 board; this is the same type of plug supported on most computers
- Load the bit stream into FPGA. Press KEY0 on the DE2 board to reset the circuit

Figure 5.2 illustrates the setup for this demonstration.

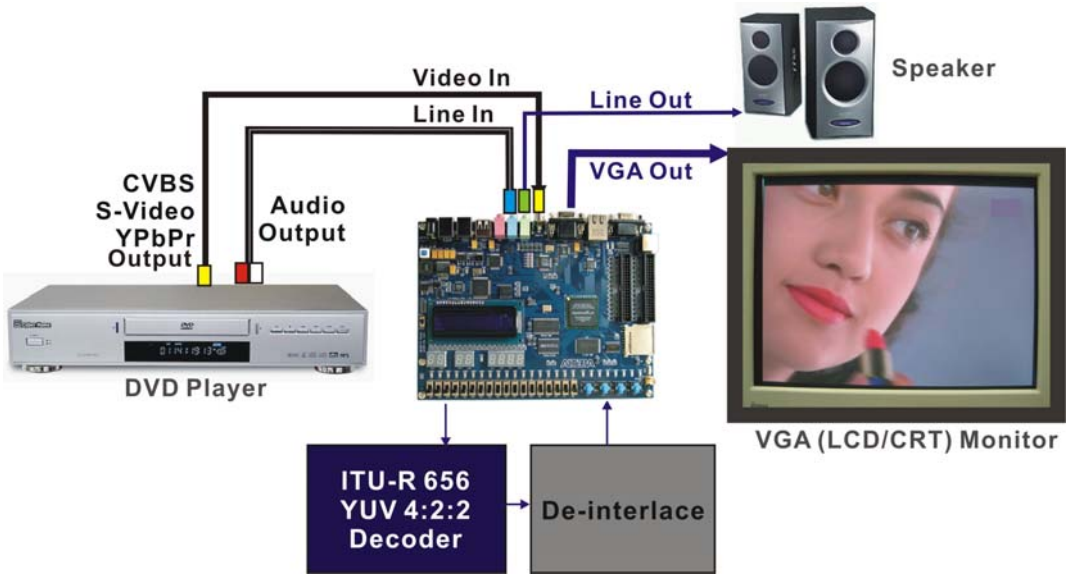

Figure 5.2. The setup for the TV box demonstration.

5.3 USB Paintbrush

USB is a popular communication method used in many multimedia products. The DE2 board provides a complete USB solution for both host and device applications. In this demonstration, we implement a Paintbrush application by using a USB mouse as the input device.

This demonstration uses the device port of the Philips ISP1362 chip and the Nios II processor to implement a USB mouse movement detector. We also implemented a video frame buffer with a VGA controller to perform the real-time image storage and display. Figure 5.3 shows the block diagram of the circuit, which allows the user to draw lines on the VGA display screen using the USB mouse. The *VGA Controller* block is integrated into the Altera Avalon bus so that it can be controlled by the Nios II processor.

Once the program running on the Nios II processor is started, it will detect the existence of the USB mouse connected to DE2 board. Once the mouse is moved, the Nios II processor is able to keep track of the movement and record it in a frame buffer memory. The *VGA Controller* will overlap the

data stored in the frame buffer with a default image pattern and display the overlapped image on the VGA display.

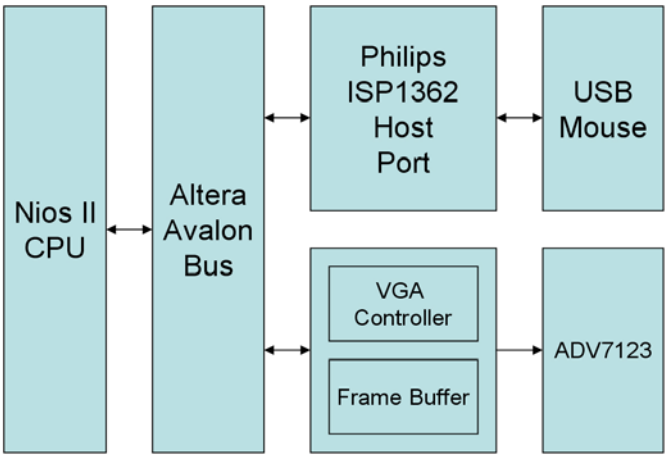

Figure 5.3. Block diagram of the USB paintbrush demonstration.

Demonstration Setup, File Locations, and Instructions

Project directory: *DE2_NIOS_HOST_MOUSE_VGA*
Bit stream used: *DE2_NIOS_HOST_MOUSE_VGA.sof*
Nios II Workspace: *DE2_NIOS_HOST_MOUSE_VGA*

- Connect a USB Mouse to the USB Host Connector (type A) of the DE2 board
- Connect the VGA output of the DE2 board to a VGA monitor (both LCD and CRT type of monitors should work)
- Load the bit stream into FPGA
- Run the Nios II and choose *DE2_NIOS_HOST_MOUSE_VGA* as the workspace. Click on the **Compile** and **Run** button
- You should now be able to observe a blue background with an Altera logo on the VGA display
- Move the USB mouse and observe the corresponding movements of the cursor on the screen
- Left-click mouse to draw white dots/lines and right-click the mouse to draw blue dots/lines on the screen.

Figure 5.4 illustrates the setup for this demonstration.

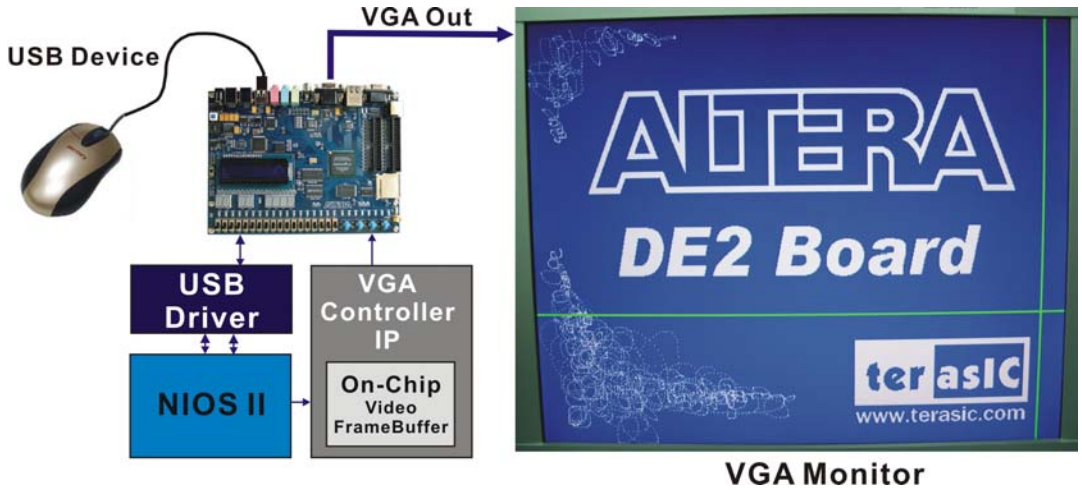

Figure 5.4. The setup for the USB paintbrush demonstration.

5.4 USB Device

Most USB applications and products operate as USB devices, rather than USB hosts. In this demonstration, we show how the DE2 board can operate as a USB device that can be connected to a host computer. As indicated in the block diagram in Figure 5.5, the Nios II processor is used to communicate with the host computer via the host port on the DE2 board's Philips ISP1362 device.

After connecting the DE2 board to a USB port on the host computer, a software program has to be executed on the Nios II processor to initialize the Philips ISP1362 chip. Once the software program is successfully executed, the host computer will identify the new device in its USB device list and ask for the associated driver; the device will be identified as a *Philips PDIUSBD12 SMART Evaluation Board*. After completion of the driver installation on the host computer, the next step is to run a software program on the host computer called *ISP1362DcUsb.exe*; this program communicates with the DE2 board.

In the *ISP1362DcUsb* program, clicking on the **Add** button in the window panel of the software causes the host computer to send a particular USB packet to the DE2 board; the packet will be received by the Nios II processor and will increment the value of a hardware counter. The value of the counter is displayed on one of the board's 7-segment displays, and also on the green LEDs. If the user clicks on the **Clear** button in the window panel of the software driver, the host computer sends a different USB packet to the board, which causes the Nios II processor to clear the hardware counter to zero.

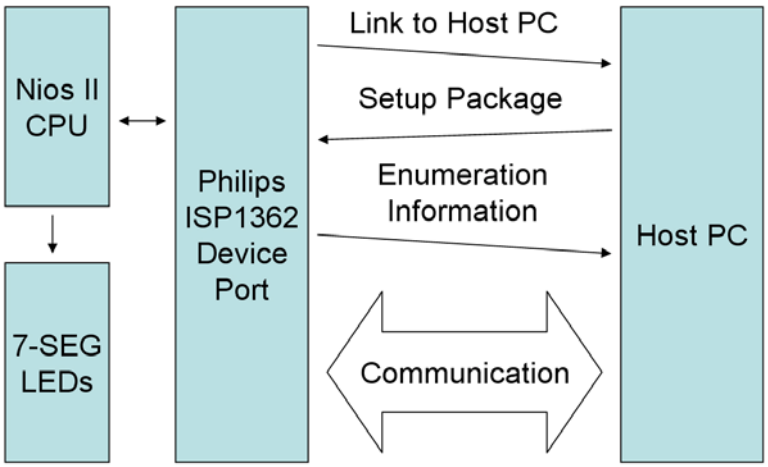

Figure 5.5. Block diagram of the USB device demonstration.

Demonstration Setup, File Locations, and Instructions

- Project directory: *DE2_NIOS_DEVICE_LED\HW*
- Bit stream used: *DE2_NIOS_DEVICE_LED.sof*
- Nios II Workspace: *DE2_NIOS_DEVICE_LED\HW*
- Borland BC++ Software Driver: *DE2_NIOS_DEVICE_LED\SW*
- Load the bit stream into FPGA
- Run Nios II IDE with HW as the workspace. Click on **Compile** and **Run**
- Connect the USB Device connector of the DE2 board to the host computer using a USB cable (type A → B). A new USB hardware device will be detected
- Specify the location of the driver as DE2_NIOS_DEVICE_LED\D12test.inf (Philips PDIUSBD12 SMART Evaluation Board). Ignore any warning messages produced during installation
- The host computer should report that a Philips PDIUSBD12 SMART Evaluation Board is now installed
- Execute the software: DE2_NIOS_DEVICE_LED\SW\ISP1362DcUsb.exe on the host computer. Then, experiment with the software by clicking on the ADD and Clear buttons

Figure 5.6 illustrates the setup for this demonstration.

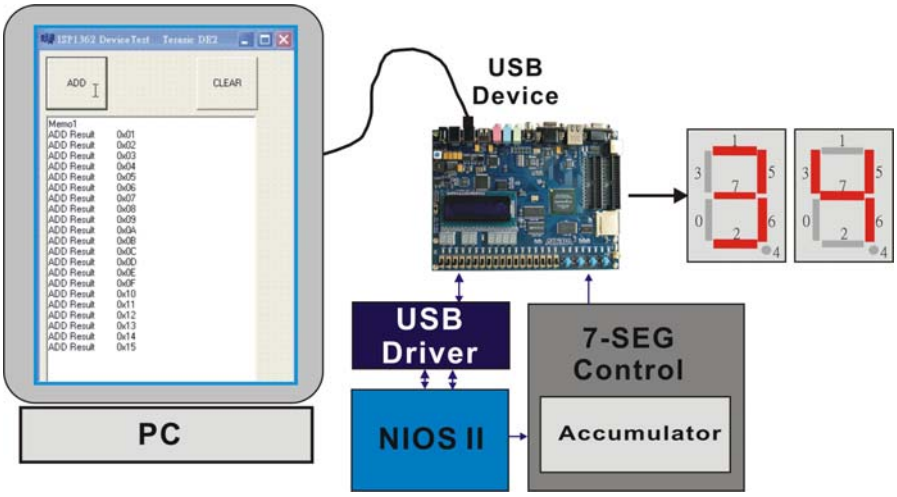

Figure 5.6. The setup for the USB paintbrush demonstration.

5.5 A Karaoke Machine

This demonstration uses the microphone-in, line-in, and line-out ports on the DE2 board to create a Karaoke Machine application. The Wolfson WM8731 audio CODEC is configured in the master mode, where the audio CODEC generates AD/DA serial bit clock (BCK) and the left/right channel clock (LRCK) automatically. As indicated in Figure 5.7, the I2C interface is used to configure the Audio CODEC. The sample rate and gain of the CODEC are set in this manner, and the data input from the line-in port is then mixed with the microphone-in port and the result is sent to the line-out port.

For this demonstration the sample rate is set to 48 kHz. Pressing the pushbutton *KEY0* reconfigures the gain of the audio CODEC via the I2C bus, cycling through one of the ten predefined gains (volume levels) provided by the device.

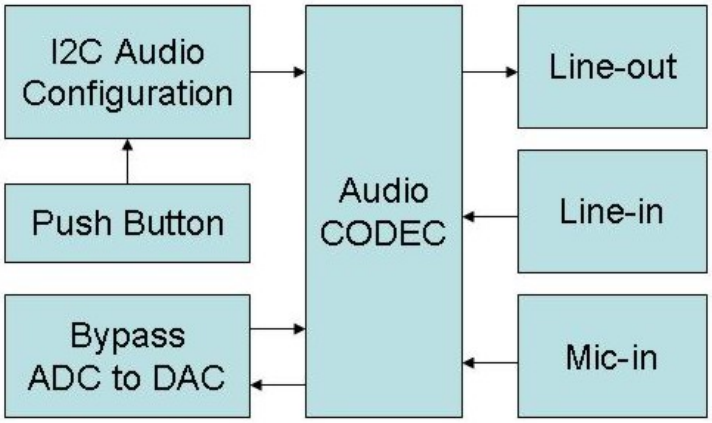

Figure 5.7. Block diagram of the Karaoke Machine demonstration.

Demonstration Setup, File Locations, and Instructions

- Project directory: *DE2_i2sound*
- Bit stream used: *DE2_i2sound.sof or DE2_i2sound.pof*
- Connect a microphone to the microphone-in port (pink color) on the DE2 board
- Connect the audio output of a music-player, such as an MP3 player or computer, to the line-in port (blue color) on the DE2 board
- Connect a headset/speaker to the line-out port (green color) on the DE2 board
- Load the bit stream into the FPGA
- You should be able to hear a mixture of the microphone sound and the sound from the music player
- Press *KEY0* to adjust the volume; it cycles between volume levels 0 to 9

Figure 5.8 illustrates the setup for this demonstration.

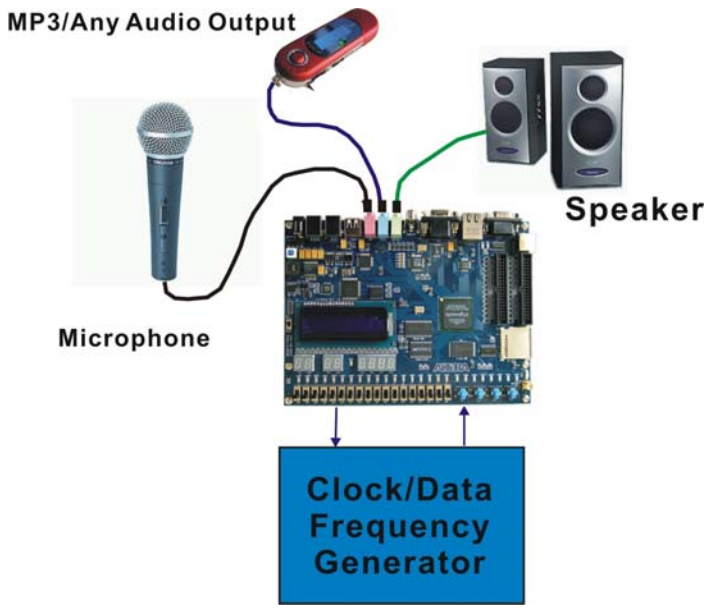

Figure 5.8. The setup for the Karaoke Machine.

5.6 Ethernet Packet Sending/Receiving

In this demonstration, we will show how to send and receive Ethernet packets using the Fast Ethernet controller on DE2 board. As illustrated in Figure 5.9, we use the Nios II processor to send and receive Ethernet packets using the DM9000A Ethernet PHY/MAC Controller. The demonstration can be set up to use either a loop-back connection from one board to itself, or two DE2 boards connected together.

On the transmitting side, the Nios II processor sends 64-byte packets every 0.5 seconds to the DM9000A. After receiving the packet, the DM9000A appends a four-byte checksum to the packet and sends it to the Ethernet port.

On the receiving side, the DM9000A checks every packet received to see if the destination MAC address in the packet is identical to the MAC address of the DE2 board. If the packet received does have the same MAC address or is a broadcast packet, the DM9000A will accept the packet and send an interrupt to the Nios II processor. The processor will then display the packet contents in the Nios II IDE console window.

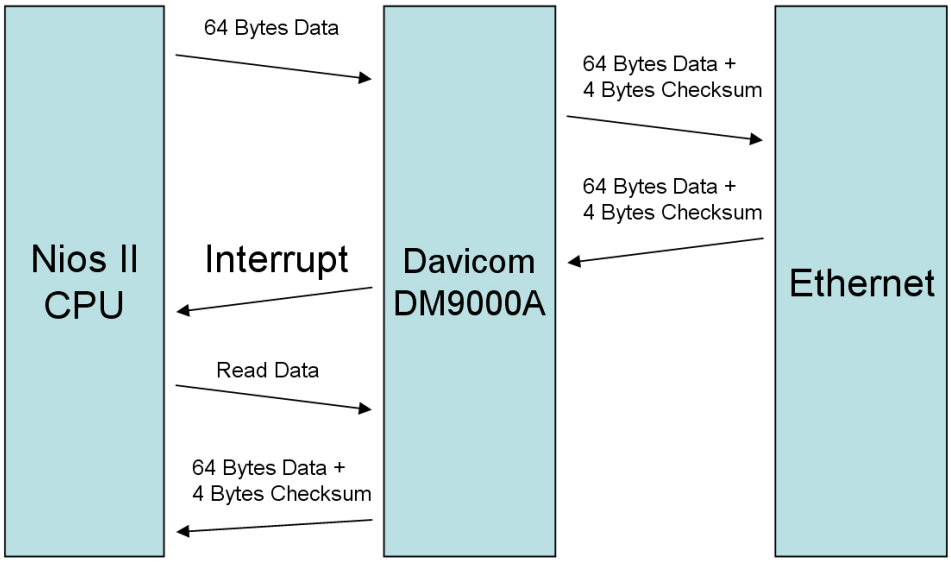

Figure 5.9. Packet sending and receiving using the Nios II processor.

Demonstration Setup, File Locations, and Instructions

- Project directory: *DE2_NET*
- Bit stream used: *DE2_NET.sof*
- Nios II Workspace: *DE2_NET*
- Plug a CAT5 loop-back cable into the Ethernet connector of DE2
- Load the bit stream into the FPGA
- Run the Nios II IDE under the workspace *DE2_NET*
- Click on the **Compile** and **Run** button
- You should now be able to observe the contents of the packets received (64-byte packets sent, 68-byte packets received because of the extra checksum bytes)

Figure 5.10 illustrates the setup for this demonstration.

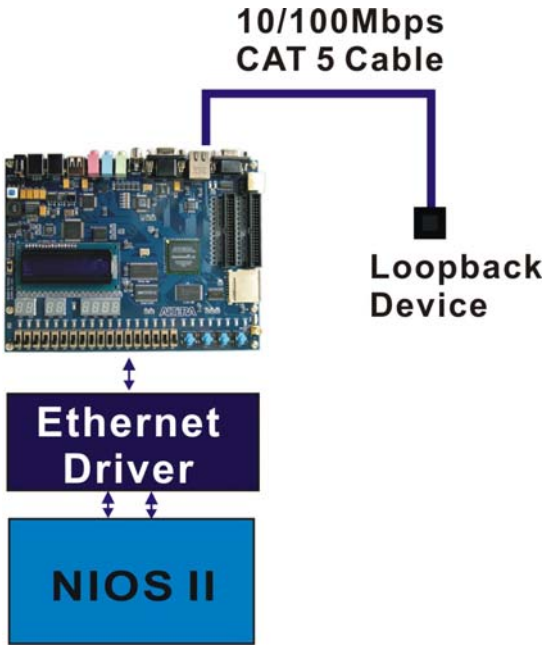

Figure 5.10. The setup for the Ethernet demonstration.

5.7 SD Card Music Player

Many commercial media/audio players use a large external storage device, such as an SD card or CF card, to store music or video files. Such players may also include high-quality DAC devices so that good audio quality is produced. The DE2 board provides the hardware and software needed for SD card access and professional audio performance so that it is possible to design advanced multimedia products using the DE2 board.

In this demonstration we show how to implement an SD Card Music Player on the DE2 board, in which the music files are stored in an SD card and the board can play the music files via its CD-quality audio DAC circuits. We use the Nios II processor to read the music data stored in the SD Card and use the Wolfson WM8731 audio CODEC to play the music.

The audio CODEC is configured in the slave mode, where external circuitry must provide the ADC/DAC serial bit clock (*BCK*) and left/right channel clock (*LRCK*) to the audio CODEC. As shown in Figure 5.11, we provide an *Audio DAC Controller* to achieve the clock generation and the data flow control. The *Audio DAC Controller* is integrated into the Avalon bus architecture, so that the Nios II processor can control the application.

During operation the Nios II processor will check if the FIFO memory of the *Audio DAC Controller* becomes full. If the FIFO is not full, the processor will read a 512-byte sector and send the data to the FIFO of the *Audio DAC Controller* via the Avalon bus. The *Audio DAC Controller* uses a 48 kHz sample rate to send the data and clock signals to the audio CODEC. The design also mixes the data from microphone-in with line-in for the Karaoke-style effects.

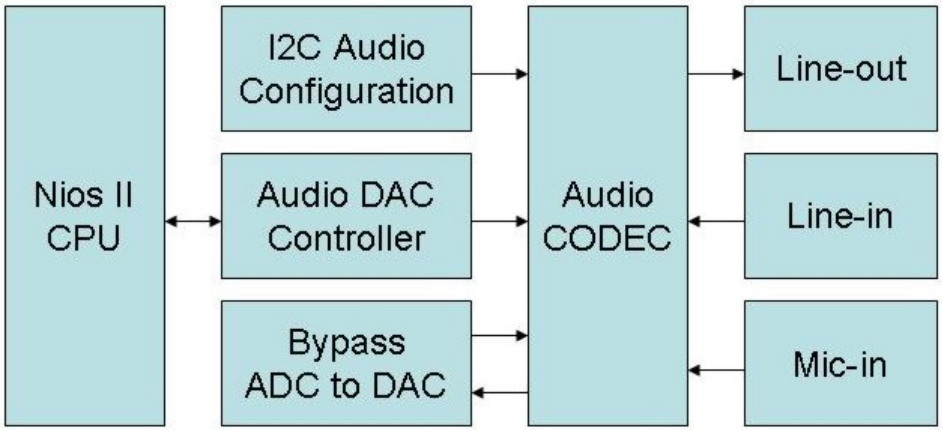

Figure 5.11. Block diagram of the SD music player demonstration.

Demonstration Setup, File Locations, and Instructions

- Project directory: *DE2_SD_Card_Audio*
- Bit stream used: *DE2_SD_Card_Audio.sof*
- Nios II Workspace: *DE2_SD_Card_Audio*
- Format your SD card into *FAT16* format
- To play a music file with this demonstration, the file must use the *48KHz sample rate* and *16-bit sample resolution* WAV format. Copy one or more such WAV files onto the FAT16-formatted SD Card. Due to a limitation in the software used for this demonstration, it is necessary to reformat the whole SD Card if any WAV file that has been copied onto the card needs to be later removed from the SD Card
- Load the bit stream into the FPGA
- Run the Nios II IDE under the workspace *DE2_SD_Card_Audio*
- Connect a headset or speaker to the DE2 board and you should be able to hear the music played from the SD Card

Figure 5.12 illustrates the setup for this demonstration.

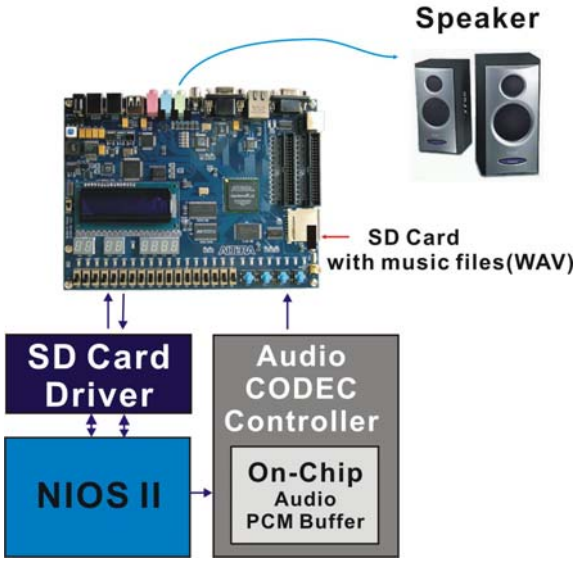

Figure 5.12. The setup for the SD music player demonstration.

5.8 Music Synthesizer Demonstration

This demonstration shows how to implement a Multi-tone Electronic Keyboard using DE2 board with a PS/2 Keyboard and a speaker.

PS/2 Keyboard is used as the piano keyboard for input. The Cyclone II FPGA on the DE2 board serves as the Music Synthesizer SOC to generate music and tones. The VGA connected to the DE2 board is used to show which key is pressed during the playing of the music.

Figure 5.13 shows the block diagram of the design of the Music Synthesizer. There are four major blocks in the circuit: *DEMO_SOUND*, *PS2_KEYBOARD*, *STAFF*, and *TONE_GENERATOR*. The *DEMO_SOUND* block stores a demo sound for user to play; *PS2_KEYBOARD* handles the users' input from PS/2 keyboard; The *STAFF* block draws the corresponding keyboard diagram on VGA monitor when key(s) are pressed. The *TONE_GENERATOR* is the core of music synthesizer SOC.

User can switch the music source either from *PS2_KEYBOAD* or the *DEMO_SOUND* block using SW9. To repeat the demo sound, users can press KEY1.

The *TONE_GENERATOR* has two tones: (1) String. (2) Brass, which can be controlled by SW0. The audio codec used on the DE2 board has two channels, which can be turned ON/OFF using SW1 and SW2.

Figure 5.14 illustrates the setup for this demonstration.

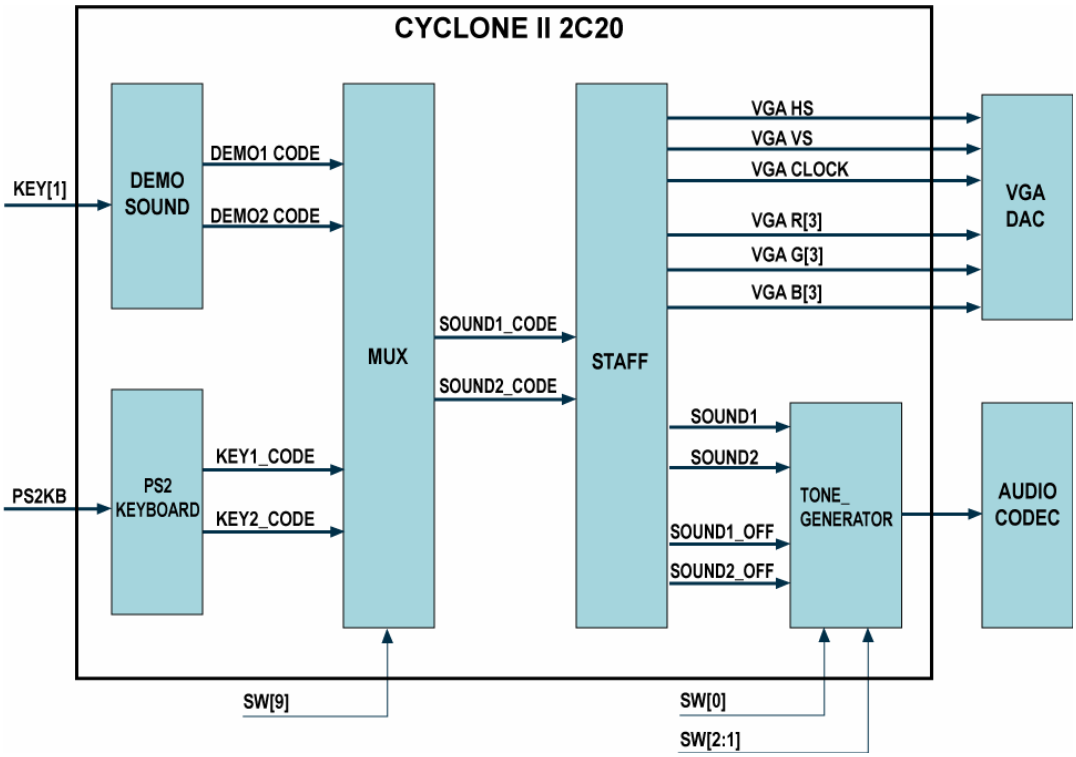

Figure 5.13. Block diagram of the Music Synthesizer design

Demonstration Setup, File Locations, and Instructions

- Project directory: *DE2_Synthesizer*
- Bit stream used: *DE2_Synthesizer.sof* or *DE2_Synthesizer.pof*
- Connect a PS/2 Keyboard to the DE2 board.
- Connect the VGA output of the DE2 board to a VGA monitor (both LCD and CRT type of monitors should work)
- Connect the Lineout of the DE2 board to a speaker.
- Load the bit stream into FPGA.
- Make sure all the switches (SW[9:0]) are set to 0 (Down Position)
- Press KEY1 on the DE2 board to start the music demo
- Press KEY0 on the DE2 board to reset the circuit

Table 5.1 and 5.2 illustrate the usage of the switches, pushbuttons (KEYs), PS/2 Keyboard.

- Switches and Pushbuttons

Signal Name	Description
KEY[0]	Reset Circuit
KEY[1]	Repeat the Demo Music
SW[0]	OFF: BRASS, ON: STRING
SW[9]	OFF: DEMO, ON: PS2 KEYBOARD
SW[1]	Channel-1 ON / OFF
SW[2]	Channel-2 ON / OFF

Table 5.1. Usage of the switches, pushbuttons (KEYs).

- PS/2 Keyboard

Signal Name	Description
Q	-#4
A	-5
W	-#5
S	-6
E	-#6
D	-7
F	1
T	#1
G	2
Y	#2
H	3
J	4
I	#4
K	5
O	#5
L	6
P	#6
:	7
“	+1

Table 5.2. Usage of the PS/2 Keyboard’s keys.

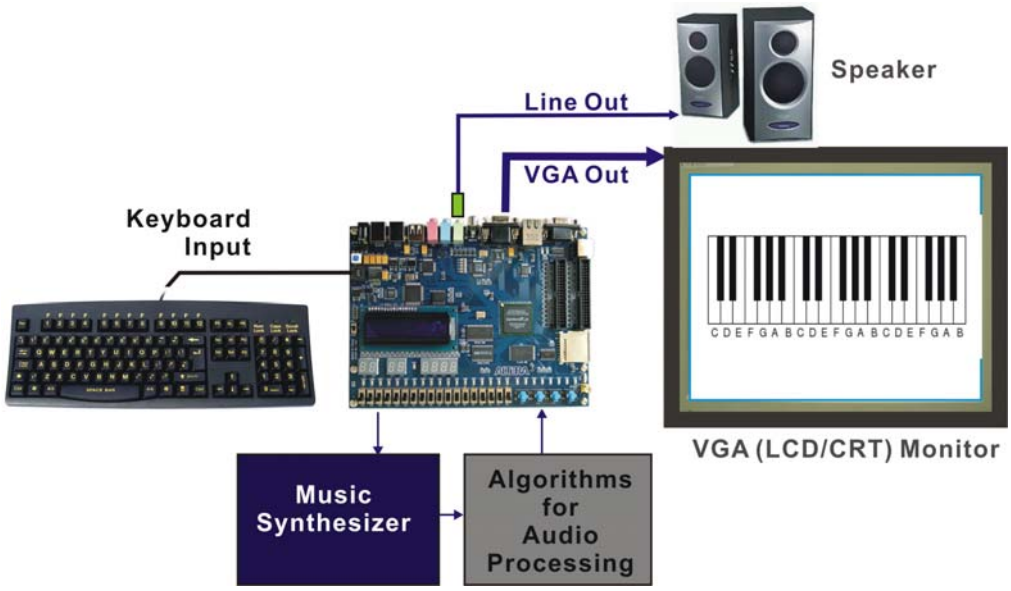

Figure 5.14. The Setup of the Music Synthesizer Demonstration.

Copyright © 2005 Altera Corporation. All rights reserved. Altera, The Programmable Solutions Company, the stylized Altera logo, specific device designations, and all other words and logos that are identified as trademarks and/or service marks are, unless noted otherwise, the trademarks and service marks of Altera Corporation in the U.S. and other countries. All other product or service names are the property of their respective holders. Altera products are protected under numerous U.S. and foreign patents and pending applications, mask work rights, and copyrights. Altera warrants performance of its semiconductor products to current specifications in accordance with Altera's standard warranty, but reserves the right to make changes to any products and services at any time without notice. Altera assumes no responsibility or liability arising out of the application or use of any information, product, or service described herein except as expressly agreed to in writing by Altera Corporation. Altera customers are advised to obtain the latest version of device specifications before relying on any published information and before placing orders for products or services.

This document is being provided on an "as-is" basis and as an accommodation and therefore all warranties, representations or guarantees of any kind (whether express, implied or statutory) including, without limitation, warranties of merchantability, non-infringement, or fitness for a particular purpose, are specifically disclaimed.